Ardabelle

GREENING THE ARTERIES OF EUROPE'S ECONOMY:

A new framework for building supply chain resilience and strategic autonomy

Preface

Economic research is moving beyond narrow environmental add-ons toward integration of ecological constraints into core economic reasoning. This discussion paper marks Ardabelle Capital's contribution to that trend, which we believe is of major significance to policy makers and business leaders alike. It seeks to translate cutting-edge economic research into actionable insights and recommendations. As an investment firm working directly with companies navigating this transformation, we wanted to contribute to this shift. Rather than claiming definitive answers, we see our role as facilitators: synthesizing insights across disciplines and translating research into practical frameworks for building resilient, low-carbon supply chains.

The report puts forward a new framework for strengthening supply-chain resilience and building greater strategic autonomy in Europe. In doing so, it joins a broader conversation anchored by Mario Draghi's 2024 report on European competitiveness — which identifies decarbonization, dependency reduction, and industrial renewal as interlocking imperatives — while bringing a distinctive focus on the convergence of resilience and sustainability as the twin foundations of Europe's next economic model. The findings, which build on Ardabelle Capital's expertise in counseling companies on their supply-chain resilience, are based on in-depth macro- and sector-level analyses, complemented by interviews with environmental economists and corporate leaders in procurement, supply chain, and sustainability. We would welcome any feedback you may have to improve our approach.

As an investment firm focused on transforming value chains into low-carbon, resilient, and competitive models, Ardabelle Capital helps already profitable industrial and mission-critical service companies accelerate their growth and ecological transition, through our strategic focus on resilient supply chains and investment strategy. Our work enables clients to tackle Scope 3 emissions while enhancing competitiveness and reinforcing industrial sovereignty. As a result, we wrote this report as a contribution to policy and academic debates on matters close to our heart.

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In brief

For mainstream economics, the environment and ecological constraints are no longer "just" a peripheral externality but have now become a part of core macroeconomic reasoning. In this new paradigm, resilience–the ability to absorb, limit losses, and bounce back–is a fundamental determinant of economic outcomes and competitiveness. It goes hand-in-hand with sustainability and sovereignty.

Strengthening resilience is particularly critical for Europe. The deep integration of its companies, especially small and medium-sized enterprises (SMEs), into global value chains has delivered growth and efficiency, but it has also made the region highly vulnerable to climate-related shocks, geopolitical tensions, and supply chain disruptions. In 2023 alone, 59 state-based conflicts were accounted for, reaching the highest level since 1946.[1] These structural dependencies undermine Europe's strategic autonomy and decarbonization efforts.

The transition is not only driven by the supply side, but also by the demand side: better resource use, extending asset lifespans, and eco-design can simultaneously reduce dependencies, stimulate innovation, and generate sustainable economic value.

This discussion paper examines how European governments and companies both large and small can "green the arteries" of European industry by redesigning value chains to be both sustainable and robust, investing in green industrial capabilities to strengthen strategic autonomy, and shifting the perception of resilience from that of a necessary cost to a source of competitive advantage.

At a macroeconomic level, that will require reducing energy dependencies, decarbonizing industry, and securing supplies of critical materials. At the micro level, firms can take critical steps to transform themselves, including with risk mapping, Scope 3 emissions reduction, relocation, digital traceability, and eco-design.

SMEs will play a pivotal role. They account for 99% of European companies and are critical hubs but remain underfunded and receive little support in their transition; only about one-sixth of their climate adaptation efforts expected for 2030 are currently funded. [2]

Taking action is of critical importance, as a central and distinctive part of our research highlights. We modeled four scenarios for the European economy to 2050 showing a range of outcomes depending on how European policy makers and businesses react to the challenges of resilience, sustainability, and strategic autonomy. These scenarios range from a "Status Quo" in which neither resilience nor sustainability are scaled up, to a "Resilient Green" scenario in which Europe redesigns supply chains that are both low carbon and able to adjust to disruptions. The two other scenarios "Fortress Brown" and "Fragile Green" are partial transitions (green without resilience and resilient without being green). They are insufficient to ensure durable stability and competitiveness. These scenarios show that the cost of inaction is very high indeed: the status quo scenario would lead to a loss of up to 16% of GDP by 2050 against a baseline of no climate impacts.[3] Even in the Fortress Brown scenario, where Europe

[1] Talebian, S., & Lager, F. (2025). Navigating a changing world order: the future of geopolitical and geoeconomic fragmentation. Mistra Geopolitics Report

[2] J.P. Morgan. (2025). *Building Resilience Through Climate Adaptation*

[3] As detailed in the methodology of the model, baseline GDP growth is set at 1% annually (average between IMF, OECD, ADEME, European Commission, NGFS and Banque de France data), from €18T in 2024 to €24T in 2050

becomes resilient but mostly concentrates on adaptation efforts, the economy ends up growing almost 14% below the baseline. By contrast, the Resilient Green scenario can positively transform the economy and increase GDP up to 14% against the baseline. This is the only scenario combining climate, growth, and sovereignty.

The exhibit below shows the range of potential outcomes from the scenarios.

European GDP in 2050 across four scenarios vs. €18T GDP 2024 baseline[4]

Exhibit 1 – Source: Ardabelle Capital interviews and analysis.

Time is critical. One of the paradoxes of the current situation is that it will take years before the extent of negative effects of inaction become visible. That lag is not fostering timely and shorter-term action. Front-loading efforts reduce long-term costs significantly; research suggests that large economies can capture up to 80% of the returns on their own unilateral decarbonization investments through avoided climate-related costs.[5] Investment in innovation is a structural multiplier that boosts both productivity and climate impact mitigation.

In a "No Green, No Resilient" scenario, Europe's 2.7 °C trajectory turns climate stress into a structural shock multiplier. Lacking green transition and adaptive infrastructure, the continent's economic, social, and ecological systems erode together. Droughts disrupt food and energy supply, floods damage housing and logistics, and forest loss weakens carbon sinks. Without investment in resilient grids and natural buffers, crises compound, raising reconstruction costs, contracting insurance markets, and deepening public debt. Uneven protection fuels inequality and migration, while repeated shocks strain institutional trust and exhaust ecosystems' capacity to absorb future extremes.

[4] As detailed in the methodology of the model, baseline GDP growth is set at 1% annually (average between IMF, OECD, ADEME, European Commission, NGFS and Banque de France data), from €18T in 2024 to €24T in 2050

[5] Bilal. A., Känzig. D. (2025). *Does unilateral decarbonization pay for itself?*

What course of action should policy makers and business leaders adopt in the face of these urgent challenges? The report concludes with several recommendations. Financial actors should channel capital into green and resilient infrastructure and supply chains, develop blended finance vehicles and resilience bonds, and support European SMEs with targeted financing instruments for decarbonization and reshoring — extending their role beyond capital provision to become active partners in the ecosystem of change.

For companies and supply chains, mapping supply chains beyond Tier 1 suppliers and establishing diversification thresholds for critical inputs will be essential. Long-term supplier partnerships that co-invest in Scope 3 decarbonization, and resilience are crucial future steps, as is embedding decarbonization requirements directly into procurement and contracting. Participation in European sectoral coalitions to pool standards and accelerate transformation is equally important.

Governments and the EU also have significant steps to take. These include launching a European Pact for Industrial Resilience that coordinates investments, regulation, and innovation; targeting public funding toward high-impact sectors such as energy, agri-inputs, and strategic manufacturing; diversifying strategic supply chains and linking public procurement to resilience criteria; and upholding the ambition of binding regulatory instruments — EU ETS, CBAM, PPWR — and Green Deal financing mechanisms.

Finally, citizens and civic groups can drive informed demand shifts, local resilience, and accountability.

The report is divided into five chapters. The first two highlight the importance of a “trinity” of resilience, sustainability and sovereignty, and examine the levers for governments and companies, both large and small, to achieve them. The third chapter consists of a detailed look at two sectors, Food and Beverage and Luxury, to identify efforts currently underway to improve resilience. Chapter four covers the four scenarios for the European economy that are Ardabelle Capital’s distinctive contribution to the ongoing economic conversation. The final chapter contains recommendations for the various stakeholders.

Ardabelle Capital welcomes feedback. This is an important and overdue conversation to be having.

1. How resilience and sustainability can become the engines of European growth

Geopolitical tensions and climate risk are no longer distant threats; they are already disrupting supply chains and the stability of financial systems. In this opening chapter, we look at the increased vulnerabilities that economies and companies face both today and, in the future, and examine what it could take to strengthen resilience.

Global risks are rising, heightening global economic volatility and affecting supply chains

The global economy is increasingly exposed to a range of vulnerabilities**.** Disruptions to global supply chains come from all directions: geopolitical tensions, armed conflicts, tariffs, natural disasters, the breakdown of ecosystems and the services they provide, and the depletion of natural resources.

The Covid-19 crisis exposed these vulnerabilities**.** Concerns about the resilience of supply stoked the broader economic anxiety[6], with retailers experiencing shortages due to panicked consumer behavior.[7] Although the performance of global supply chains was impressive in many respects[8], many commentators dubbed the post-Covid economy the "new normal."[9]

While the Covid-19 crisis has passed, underlying vulnerabilities remain. They include:

Geopolitical risk

A geopolitical risk index constructed by researchers Caldara and Iacoviello using newspaper data is not at its highest recorded levels, but it is currently trending upwards. Other indicators suggest an increasing sense of uncertainty. UNCTAD notes that the Economic Policy Uncertainty Index "reached its highest levels this century" in early 2025, with trade-policy shocks and tariff announcements a key driver of market turbulence and growth downgrades.[10] Europe's exposure to geopolitical risks in energy and critical materials has been explicitly documented by the European Commission (Strategic dependencies and capacities, SWD, 2021): strategic dependencies for rare earths, magnesium and PV modules "stem from a strong concentration of global production in China," with limited options for rapid diversification or substitution.[11] This vulnerability became starkly evident in 2022 with the fossil fuels crisis; the Commission's 2025 roadmap to end Russian energy imports reports that, despite progress, the EU still imported 52 billion cube meters of Russian gas in 2024 (~20% of all European imported gas) and remained reliant on Russian oil and enriched uranium in several member states,

[6] Baker, Scott R., and al. (2020). COVID-induced Economic Uncertainty, *NBER Working Paper*
[7] OECD. (2020). COVID-19 and the Food and Agriculture Sector: Issues and Policy Responses
[8] In an interview (Mecalux Group. (2022). *Supply Chain Lessons from the Pandemic*), Yossi Sheffi stated that « supply chains did not fail », stating the fact that no major disruptions to the food supply chain actually happened.
[9] See, for example, McKinsey & Company. (2020). *Resetting supply chains for the next normal* and Yossi Sheffi, 2020, *The New (Ab)Normal*.
[10] UNCTAD. (2025). *Global Trade Update*
[11] Commission Staff Working Document. (2021). *Strategic dependencies and capacities*,

underscoring the lingering exposure to supply coercion and disruption risks. Geopolitical volatility is also heightening perceptions of global risk. The World Economic Forum's Global Risks Report 2025 identifies "state-based armed conflict" as the top immediate global risk. Nearly one-quarter of surveyed experts ranked it the single biggest risk "to present a material crisis on a global scale" in 2025, ahead of extreme weather and geoeconomic confrontation.[12]

At the same time, there is broad consensus among experts that we have entered a new era of sustained geopolitical uncertainty–one that is unlikely to abate in the foreseeable future – making it necessary to think about environmental policies in a context of reduced international cooperation. The post–Cold War international order, once a foundation for cooperative frameworks, can no longer be taken for granted: in 2023, the number of state-based conflicts reached its highest level since 1946, with almost 60 active countries.[13]

Global value chains are already experiencing the impacts of recent shocks. The Red Sea crisis in 2023 forced the rerouting of container ships, extending transit times between Asia and Europe by 10 to 14 days.[14] In energy markets, European wholesale gas prices surged by 163%[15] in 2022, reflecting the continent's heightened vulnerability to geopolitical disruptions. Meanwhile, drought conditions attributed partly to El Nino have significantly constrained traffic through the Panama Canal,[16] creating further bottlenecks for global trade until recently.

Climate risks

Climate change is no longer a distant threat; it disrupts supply chains and the stability of financial systems. Global temperatures have risen by 1.24°C compared to 1850-1900, and scientists are warning that the 1.5°C target set in 2015 in Paris will no longer be attainable.[17] The heightened probability of disasters adds to the damage from the gradual increase in global temperatures, such as rising sea levels and desertification.[18] The frequency of heatwaves is expected to increase, as is the magnitude of tornadoes, and droughts. While improvements in disaster preparedness have helped reduce mortality rates, economic losses are accelerating. For example, the January 2025 California wildfires are preliminarily assessed as the costliest event ever recorded in the EM-DAT disaster database[19], with estimates exceeding $250 billion.[20]

A feedback loop is already visible across high-risk regions in the United States, Australia, and southern Europe: first, insurers retreat from regions facing higher climate risks. Next, home values decline, eroding household wealth. Banks respond by tightening credit and pulling back from mortgage issuance. Soon after, municipal budgets weaken, new construction halts, and broader financial contagion takes hold.

Drawing on the taxonomy developed by the Task Force on Climate-related Financial Disclosures[21], firms face two broad categories of climate-related risk. The first comprises "physical risks", meaning the direct consequences of a changing climate. These can be differentiated into "chronic risks"–slow-onset harms such as declining agricultural yields or

[12] World Economic Forum. (2025). *Global Risk Report*
[13] Talebian, S., & Lager, F. (2025). Navigating a changing world order: the future of geopolitical and geoeconomic fragmentation. Mistra Geopolitics Report
[14] Crisis Group - The Houthis' Red Sea Attacks Explained
[15] "The gas price shock: never again?", *Bulletin de la Banque de France*. (2024)
[16] "Drought behind Panama Canal's 2023 shipping disruption "unlikely" without El Nino", *Carbon Brief*
[17] G. Foster, S. Rahmstorf. (2025). Global Warming has Accelerated Significantly. *Preprint*.
[18] IPCC
[19] UNDRR. (2025). *GAR 2025: Resilience pays*
[20] *LA Times*. (2025). "Estimated cost of fire damage balloons to more than $250 billions"
[21] Task Force on Climate-related Financial Disclosures, *Guidance on Metrics, Targets, and Transition Plans*

sea-level rise–and "acute risks", such as the heightened frequency and severity of extreme events, including floods, wildfires, and heatwaves. The second category encompasses "transition risks", which arise from the shift to a low-carbon economy. Within this category, legal risks may materialize when firms fail to comply with increasingly stringent and costly regulations; market risks could emerge as lower-emission competitors gain cost advantages or capture greater demand. Furthermore, reputational risks occur when stakeholders penalize firms perceived as contributing to climate change, for instance through boycotts.

Climate inaction thus carries a steep price tag–not just for the planet, but for the global economy**.** Estimates of the social cost of carbon, which quantify the monetary damage of emitting one ton of CO_2, have continuously been revised upwards as economic modeling has evolved to more accurately reflect environmental costs and climate-related risks. Currently, it is estimated that emitting a ton of carbon will cost society $183 in the future, not accounting for the increasing cost of related environmental policies,[22] To put this into perspective, global emissions reached 41.6 billion tons of CO_2 in 2024. As carbon pricing mechanisms tighten globally, the economic case for unilateral decarbonization strengthens: by acting early, Europe can reduce its exposure to escalating carbon costs, avoid mounting climate damage, and secure competitive advantages in emerging low-carbon markets—delivering net economic gains even if other major economies delay their transitions.[23] These impacts unfold through multiple channels, including the well-documented decline of agricultural yields[24] or the effect of frequent heatwaves on labor productivity.[25]

Moreover, the global economy is operating under increasing pressure on planetary boundaries–the threshold over which human pressure on critical global processes creates large, abrupt and irreversible environmental changes. [26] Out of the nine planetary boundaries identified by researchers led by the Swedish scientist Johan Rockström, six had already been crossed by 2023, considerably increasing the risk of tipping points.[27] Many scientists consider now that the seventh was crossed at the end of 2025, as ocean acidification reached critical levels. Such assessments help reveal the economic significance of natural processes we have long taken for granted. Chief among them are ecosystem services – the direct and indirect benefits ecosystems provide, such as water supply – which are critical to economic activity despite being largely unpaid for. Attempts to monetize these services have underscored their importance: in the euro area, 72% of non-financial corporations are critically dependent on these services. That's hardly surprising when considering that just ten ecosystem services in the EU28 generated annual benefits worth €234 billion[28] – roughly 1.2% of the EU's GDP.[29]

One of the most immediate threats stems from the accelerating depletion of natural resources. The timeline for their exhaustion is uncertain, but Europe is especially vulnerable. The European Union could begin feeling the effects of oil scarcity as early as 2030[30], due to declining production capacity among its key suppliers and rising global demand, notably from fast-

[22] For an overview of the different types of carbon pricing, see France Stratégie. (2025). *La nouvelle trajectoire de la valeur de l'action pour le climat*

[23] A. Bilal, D. R. Känzig. (2025). Does Unilateral Decarbonization pay for itself? *NBER Working Paper.*

[24] IPCC. (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability*

[25] CNP. (2023.) *Bilan des crises : productivité, compétitivité et transition climatique.*

[26] For example, increased CO_2 emissions increase the acidity of the ocean water. This in turns impact the marine ecosystems, unable to adapt to this sudden acidification, which then threatens the ocean's role as a carbon sink.

[27] Stockholm Resilience Centre. (2023). *Earth beyond six of nine planetary boundaries*. Stockholm

[28] Eurostat. (2021). *Accounting for ecosystems and their services in the European Union (INCA)*

[29] European Central Bank. (2024). *Economic and Financial Impact of Nature Degradation and Biodiversity Loss.*

[30] Shift Project. (2020). *The EU can expect to suffer oil depletion by 2030*

growing Asian economies. The shift to low-carbon alternatives brings its own set of vulnerabilities–albeit less severe than fossil fuel dependency. For instance, if Europe continues decarbonizing without securing diversified supply chains, lithium–a vital input for batteries–could face critical shortages by 2030.[31]

Risks from shifting trade patterns

Decades of expanding global value chains are beginning to reverse. Regulatory changes in the United States, the European Union, and elsewhere are highlighting a shift towards economic nationalism, making offshoring potentially less profitable. Until recently, the prevailing logic was that efficiency, and growth came from dispersing production across a tightly linked global network. Global trade in 2024 reached about 45 times its 1950 level[32], increasing at more than double the rate of the global economy growth.[33] The increase in global trade has been largely driven by the fragmentation of production across countries; unfinished products – products that will be used to produce final goods and services – account for 70% of global trade.[34] Yet, this interdependence has revealed significant and systematic vulnerabilities in global value chains, as localized climate-related shocks propagate rapidly through complex supplier interdependencies.[35] One example was the 9.1-magnitude Tōhoku earthquake that hit Japan in 2011. Its ripple effects were felt worldwide. Multinational corporations like Intel and General Motors–despite having few direct suppliers in the affected area–faced the risk of production shutdowns lasting several weeks. Similarly, when Thailand was hit by floods in 2011, Swedish manufacturing firms that depended indirectly on Thai suppliers for critical components–such as electronics and automotive parts–experienced severe disruptions in output, even though they had no direct operations or contractual relationships in the affected region.

The urgent need to strengthen resilience in national economies and companies

As geopolitical tensions and climate risks intensify, resilience is rising to the top of the agenda for both companies and governments.[36] Resilience is not a new concept–because shocks are not new. Originally rooted in physics, the term describes a material's capacity to absorb stress and return to its original form. In the context of countries or firms, resilience refers to the ability to absorb external shocks, limit disruption to economic activity, and recover swiftly. While the theme of resilience has gained renewed attention in recent years, it has been tested repeatedly throughout the 20th century–not only during the Covid-19 crisis, but also in the face of numerous natural disasters and geopolitical upheavals.

Resilience metrics typically encompass three key dimensions: the magnitude of the initial impact, the speed of recovery, and the extent of recovery. For firms, the magnitude can be

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[31] INEC, Capgemini Invent. (2022). *Stratégie Nationale Bas-Carbone sous Contrainte de Ressources.*

[32] WTO, *Evolution of trade under the WTO: handy statistics*

[33] Based on numbers by the Maddison project. Global trade's rapid expansion had already stalled after the 2008 crisis: although global trade continues to expand and reached its highest level in 2024, with a volume of $33 trillion[33], the period between 2020 and 2024 marks the slowest half-decade of growth since the 1990s. The slowdown was already evident in 2015-2019, with global trade growth of just over 3%, well below past levels between 5% and 7%.

[34] World Economic Forum. (2021). *These 3 charts show how international trade works – and the current state it's in*

[35] Bekkers, E., Keck, A., Koopman, R., & Nee, C. (2022). *Climate risks and global value chains: The impact of the 2011 Thailand flood on Swedish firms*. VoxEU Centre for Economic Policy Research.

[36] See for example, McKinsey, "Geopolitics and the geometry of global trade"

assessed by the decline in output or reduction in supplier orders following a shock.[37] [38] At the national level, it might be measured by economic losses or mortality rates resulting from natural disasters.[39] The speed of recovery refers to how swiftly essential infrastructures or services are restored–such as the number of days critical systems remain non-operational. The extent of recovery evaluates whether systems return to their pre-shock performance levels or stabilize at a diminished capacity. For instance, during the pandemic, a key resilience indicator was whether the global economy rebounded to its pre-crisis GDP levels.[40]

Strategies to increase resilience typically mean building redundancy, flexibility, and a culture of corporate responsiveness:

- **Redundancy** often takes the form of high inventory levels, a buffer that keeps operations running when disruptions strike. During the Covid-19 crisis, French companies with the largest inventories weathered the shock best, maintaining production while others stalled.[41] Redundancy buys time: when the 2011 earthquake hit Japan, Intel was able to minimize disruption by tapping into its own stockpiles and identifying hidden inventories across its N-tier supplier network.[42]
- **Flexibility** is about optionality. Having multiple (or quickly mobilizable) supplier options avoids overreliance on any single region. This is no longer theoretical: Indian manufacturers for instance, are deliberately sourcing inputs from higher-cost suppliers in low-flood risk zones.[43] Regulatory risk is also driving shifts. Mattel, for example, is actively reducing exposure to China, aiming for no more than 25% of its inputs from a single country.[44] And in the pharmaceutical sector, companies across the OECD are investing in alternative sourcing strategies to reduce dependency on geopolitically distant partners.[45]
- **A culture of responsiveness** is equally critical. Resilient organizations empower teams to act fast, anticipate risks, and adapt in real time. General Motors' response to the 2011 earthquake is a case in point: despite facing disruptions across 118 parts, GM managed to avoid major delivery delays thanks to teams working around the clock.[46] As Henkel's Chief Procurement Officer puts it, "in the end, it is about the mindset and ability of everyone to quickly sense and react."[47] Walmart's exceptional responsiveness during Hurricane Sandy – outpacing the Federal Emergency Management Agency (FEMA) – reflects years of investment in prospective analysis and scenario planning.[48]

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[37] G. Khana, N. Morales, N. Pandalai-Nayar. (2022). Supply Chain Resilience : Evidence from Indian Firms. *NBER Working Paper*

[38] J-N. Barrot, J. Sauvagnat. (2016). Input Specificity and the Propagation of Idiosyncratic Shocks in Production Networks. *Quarterly Journal of Economics*.

[39] UNDR*R*.(2025). *Global Assessment Report*

[40] IMF. (2020). *World Economic Outlook, October 2020: A Long and Difficult Ascent*

[41] R. Lafrogne-Joussier, J. Martin, I. Méjean. (2023). Supply Shocks in Supply Chains : Evidence from Early Lockdown in China

[42] Yossi Sheffi. (2016). *The Power of Resilience*

[43] J. Castro-Vincenzi, G. Khanna, N. Morales, N. Pandalai-Nayar. (2025). Weathering the Storm: Supply Chains and Climate Risk. *NBER Working Papers*.

[44] Cawthon, H. (2025). *Mattel leverages diversified supply chain amid new China tariffs*. *Supply Chain Dive*

[45] OECD. (2025). *OECD Supply Chain Resilience Review*.

[46] Yossi Sheffi. (2016). *The Power of Resilience*

[47] McKinsey. (2022). *Achieving Supply Chain Resiliency in Consumer Goods Amid Disruptions*

[48] Steven Horwitz, *Walmart to the rescue – Private enterprise's response to hurricane Katrina*

Such strategies come at a cost, but resilient supply chains tend to fare better. First, because disruptions to supply chains pose a considerable reputational risk.[49] In one survey, 60% of senior and supply-chain procurement executives said resilience in their supply chain was more important than speed and efficiency, while most of them reported that disruptions damaged the company's brand.[50]

Resilience has become a cornerstone of climate adaptation strategies. As extreme weather events become more frequent and severe and transition risks increase, companies must prepare not only for direct impacts on their own operations, but also for disruptions across their supply chains. The ability to absorb and recover from such shocks now serves as a financial hedge, protecting revenue, preserving market share, and securing long-term value in an increasingly volatile environment. The market has already taken into account this hedge: a J.P. Morgan analysis shows that every $1 spent on climate adaptation and resilience has a return on investment (ROI) of between $2 and $43.[51] These high returns reflect avoided damage, reduced disruption costs, and improved long-term economic performance, reinforcing the argument that proactive investment in climate resilience enhances financial stability while supporting sustainable growth. For example, a World Economic Forum study highlights several technologies essential for the food and agriculture sector to adapt to declining crop yields, including biotechnologies that enable more precise and targeted input use, and the development of novel farming systems designed to operate with significantly less water, in anticipation of increasing scarcity.

What works at the firm level also holds for Europe as a whole: resilience is becoming the cornerstone of the continent's strategy to implement its environmental goals. Europe imports a significant part of its emissions: of the 4.8 billion CO_2 tons that make up its total carbon footprint, 1.9 billion tons are generated outside the EU.[52] Reducing dependence on foreign inputs is therefore not only a resilience strategy, but a pathway to decarbonization, especially given Europe's cleaner electricity mix; fossil fuels make up 39.5% of Europe's energy mix compared with the global average of 60.7%.

Resilience, sustainability, and economic performance

Investments in response to climate change fall into two categories[53]:

- Mitigation, which aims to reduce future environmental damage by addressing the root causes of climate change. Examples include the Paris Agreement's 1.5°C target and corporate sustainability strategies.
- Adaptation, which focuses on adjusting to the expected impacts of climate change, such as rising temperatures or extreme weather events.

Historically, mitigation has received a larger share of climate investments, partly because mitigation and adaptation were often viewed as substitutes–either prevent the risk or adapt to it. This perception was reinforced by the fact that some adaptation solutions can worsen the problem they aim to address. Air conditioning, for instance, helps people cope with heat but contributes to local warming and higher energy use.

[49] Hau L. Lee. (2004). *The Triple-A Supply Chain,* Harvard Business Review
[50] GEP / The Economist, *The Business Cost of Supply Chain Disruption*
[51] J.P. Morgan. (2025). *Building Resilience Through Climate Adaptation*
[52] Eurostat
[53] Tett, G. (2024). *Wetlands and the need for adaptation in climate resilience*. *Financial Times*.

While mitigation remains essential, adaptation has become equally unavoidable, as the effects of climate change are no longer a distant threat but a present reality. Firms and governments alike need to adapt to climate change. This is a significant undertaking: it is estimated that climate adaptation finance is only at one-sixth of expected needs by 2030.[54] But as climate change unfolds, the urgency becomes clear and adaptation strategies more popular: the MSCI ACWI IMI Extreme Weather Industrial Solutions Index that tracks the performance of a set of companies associated with products and services used in day-to-day life to cope with extreme heat or cold has risen by about 210% between January 2018 and June 2025, while the MSCI World Index only increased by a little less than 130%.[55] Additionally, the notion that mitigation and adaptation are inherently substitutes is increasingly being challenged: many nature-based adaptation solutions–such as agroecological practices–not only build resilience but also contribute to climate change mitigation.

Our research examines more deeply the relationship between resilience, sustainability, and economic performance. Observable patterns are already emerging that show how these forces can serve as engines of Europe's future growth.

First, resilience reduces the cost of crises. A resilient economy can withstand climate shocks, energy disruptions, and trade tensions. This limits business closures, protects jobs, and reduces fiscal bailouts–freeing resources for productive investment. During the Russian energy crisis, €540 billion were spent in the European Union shielding consumers from rising energy costs, of which Germany alone accounted for €158 billion.[56] Of course, the amount spent also depends on the generosity of fiscal policy; Germany's especially large bill was largely due to its high dependence to Russian gas. A little less than 25% of its energy mix was made up of gas in 2022, with Russian gas accounting for 55% of gas imports.[57] Building energy resilience cuts costs in case of high price variations or resource depletion.

Second, resilience and sustainability drive innovation. Green transitions unlock new industries: cleantech, circular economy, bioeconomy, and sustainable transport. These are labor-intensive and innovative-rich, creating quality jobs across Europe. Innovation in green tech has become a strategic path to future leadership: the number of green patent applications has grown considerably, from roughly 40,000 applications at the end of the 1990s globally to 140,000 in 2018 and peaked in 2012 at 180,000.[58] Northern and Western Europe score the highest with the US in terms of patent applications per million inhabitants. This patenting activity yields broader economic benefits, although not more than "non-green" patents: a 7% increase in the number of green patents filed is estimated to increase GDP by 0.14% after five years.[59] This broader economic benefit goes notably through job creation.

Third, resilience strengthens industrial sovereignty. Resilient supply chains support strategic autonomy, thus improving Europe's position on the geopolitical scene. Production that is both localized and decarbonized drives reindustrialization in regions left behind–revitalizing communities and diversifying growth sources. One example is the emerging "Battery Valley," in the Hauts-de-France region, which has successfully attracted four major battery gigafactories, three of which focus on lithium-ion technology. This marks a key step in the region's ambition to undergo a "third industrial revolution," following decades of de-industrialization. The initiative is revitalizing the local economy and positioning the region at the heart of Europe's

[54] J.P. Morgan. (2025). *Building Resilience Through Climate Adaptation*
[55] Data from MSCI
[56] Bruegel. (2023). *National fiscal responses to the energy crisis*
[57] Clean Energy Wire. (2024). *Germany, EU remain heavily dependent on imported fossil fuels*
[58] Wiiw. (2023). *Patents as green technology barometers: trends and disparities*
[59] IMF. (2023). *Green Innovation and Diffusion*

green industrial transition. Combined with the surrounding automotive ecosystem, the battery industry is expected to generate between 20,000 and 25,000 jobs, driving significant employment and economic renewal.[60]

Fourth, resilience and sustainability build trust, stability, and investment confidence. Public trust rises when green growth delivers tangible results. A credible transition strategy attracts long-term capital, creating a virtuous cycle of confidence, growth, and support for reform. Sweden is one country that has successfully implemented an ambitious environmental policy through an early implementation of the carbon tax in 1991, while still maintaining solid GDP growth (GDP grew by more than 50% in real terms between 1990 and 2015).[61] The success of this policy created wider confidence in the population: a 2021 EIB survey showed that 76% of Swedish people were in favor of stricter government measures that impose changes in people's behaviors.[62]

Fifth, sustainable policies have a concrete economic impact. Every €1 in green public investment can generate more in GDP and job creation than fossil-based sectors. The multiplier (how much more the economy overall gains than what was spent) of green-renewable energy is higher than for non-eco-friendly energy, as well as providing a more persistent impact over the years.[63] Sustainable policies also generate more jobs for the same level of investment: for every dollar invested in solar photovoltaic energy, 1.5 times more jobs are created than if that dollar were invested in fossil fuels. This is not limited to power production, as ecosystem restoration also creates 3.7 times as many jobs as oil and gas production per dollar.[64]

Finally, resilience and sustainability promote competitiveness through efficiency. Sustainable economies reduce dependency on fossil fuels and raw materials. Efficiency gains and sustainability alignment boost export competitiveness, profitability, and investment attractiveness. They also mitigate risks related to price volatility of scarce resources.

Improving resource efficiency means using fewer inputs than competitors, while also reducing exposure to resource price volatility. This dual benefit creates a significant cost advantage for firms that choose to innovate. The impact is particularly relevant in manufacturing, where raw materials represent a substantial share of operating costs. As Europe seeks to reindustrialize and strengthen its economic base, this becomes even more critical. In the steel industry, for instance, raw materials account for approximately 67% of total production costs[65], highlighting the strategic importance of efficiency in ensuring competitiveness. In another example, Unilever claimed to have saved €1 billion in energy efficiency projects between 2008 and 2024.[66]

In short, resilience protects value. Sustainability creates value. Resilience and sustainability are no longer just buffers against disruption; they are emerging as strategic levers for building a stronger, more innovative, and competitive European economy. What are European companies and SMEs doing to improve resilience and sustainability? And what should they do? We look at these questions in the following part.

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[60] Natixis. (2024). *Strategic autonomy: The opportunities of ecological transition*.
[61] Tax Foundation Europe. (2020). *Looking Back on 30 Years of Carbon Taxes in Sweden*
[62] EIB. (2021). *76% of Swedish people in favor of stricter government measures to address the climate emergency*
[63] *Building back better: How Big Are Green Spending Multipliers?*
[64] World Economic Forum. (2021). *Why do green investments create more jobs? Experts explain*
[65] European Commission. (2020). *Production costs from iron and steel industry in the EU and third countries*
[66] Unilever. (2024). *Why we've updated our Climate Transition Action Plan*

2. Europe's resilience: challenges and levers for policy makers and business leaders

Europe needs to invest in a resilient and sustainable future both because it is particularly exposed and because these are the engines of Europe's future green growth. In this chapter, we examine in more detail the main challenges facing policymakers and companies–both large corporations and small and medium-sized enterprises (SMEs)–as they look to strengthen resilience, and the levers that can help them do so.

At the macroeconomic level, increasing Europe's resilience implies increasing economic independence

Europe's path to resilience needs to address both sides of the risk equation: becoming a clean powerhouse (mitigation) and strengthening its capacity to withstand shocks (adaptation). In practical terms, this means accelerating emission reduction efforts while also increasing resilience against vulnerabilities in upstream supply chains by lowering reliance on critical and unstable inputs. Achieving this dual objective will require the EU to pursue multiple initiatives simultaneously at the macro level. These are: decarbonizing energy, decreasing Europe's reliance on raw materials, and transforming the industrial fabric towards strategic sectors

Decarbonizing energy

Energy is a substantial challenge for Europe, as it is both a large contributor to global emissions and as a sovereignty risk. Fossil fuels–coal, oil, and natural gas–still make up 70% of Europe's overall energy mix, compared to 81% of the world's global mix.[67] Power generation alone accounts for 30% of global CO_2 emissions, primarily because of fossil fuels, making it a key leverage point for decarbonization. In Europe, oil and coal are responsible for 42% and 26% of energy-related CO_2 emissions, respectively. Beyond emissions, these fuels pose a strategic risk: Europe has minimal reserves and accounts for just 4% of global oil production while consuming 13%. The same holds for natural gas (6%) and coal (3%) reserves. This makes Europe vulnerable to an interruption of supply, or to price variations. Some of the competitiveness loss is already linked to the price of fossil fuels and natural gas prices in Europe are approximately three times higher than in the United States.[68]

These vulnerabilities pose a direct threat to European sovereignty. For example, Europe's heavy reliance on Russian natural gas–43% of its supply in 2021–undermined its ability to respond decisively to geopolitical aggression. The threat of cutting off Russian gas was less credible, and as of 2024, there is still no EU-wide ban, despite reducing dependency to 18%.[69]

Greater electrification is the first lever to decarbonize Europe's energy mix. Fossil fuels make up 40% of Europe's electricity mix, considerably less than its energy mix, and there are considerable variations; in France, for example, less than 10% of electricity is generated using fossil fuels. While nuclear and renewables come with their own dependencies–such as lithium

[67] Data from the International Energy Agency
[68] Eureletric, *US vs. EU : the ultimate prices showdown*
[69] Bruegel. (2025). « Europe urgently needs a common strategy on Russian gas »

or uranium–they are less acute. For example, although 40% of Europe's uranium is imported, stockpiles could last for years in a supply crisis. In contrast, fossil fuel reserves would be depleted within weeks, underscoring the urgency of a cleaner, more secure energy transition.[70]

Substitution is also a powerful lever to reduce Europe's fossil fuels dependency. Full electrification is not feasible, for example in transportation; heavy transport sectors–such as shipping, responsible for 14% of EU transport emissions[71]–are particularly hard to decarbonize through electrification alone. Part of the solution is to find alternative low-emission fuels, such as biofuels derived from biomass. Biomass comes from agriculture, forestry, fisheries and aquaculture, and waste–resources that Europe does not lack. However, biomass only works as a significant electricity source in combination with electrification and reduced consumption; supplying enough biomass fuel to cover France's electricity needs would require more than all of the country's forestland area.[72]

Finally, greater energy efficiency can be achieved: studies have highlighted the existence of an energy-efficiency gap, with far fewer energy-saving solutions being adopted than would be economically optimal. Various barriers explain this gap, including limited access to capital, short-term planning, and lack of incentives. Addressing these issues will require targeted policies to stimulate innovation and accelerate the adoption of resource-efficient technologies.

Decreasing Europe's reliance on raw materials

Critical raw materials also represent a dependency for which Europe must find substitutes**.** The EU's latest list of critical raw materials highlights several strategic vulnerabilities.[73] Gallium, essential for photovoltaic cells, is 80% processed in China; beryllium, used in electronics, communications, and car manufacturing, is 88% extracted in the United States; and phosphate rock, vital for producing mineral fertilizers, is 48% extracted in China. Many of these materials currently lack viable substitutes, underscoring the need for sustained innovation.

These vulnerabilities are already creating challenges: since early 2022, 37% of EU importers have reported difficulties in accessing key commodities and raw materials like steel, copper, fossil fuels, and lithium.[74] These materials are not only vital to current production but also critical to the EU's green and digital transitions. For some strategic green technologies–such as lithium-ion batteries, wind turbines, and electric traction motors–the EU supplies just 1% or less of certain key inputs, highlighting its limited self-sufficiency in crucial areas.[75]

Greater resource efficiency can make the European economy more competitive, more sustainable and potentially more innovative. In many cases, efficient use of resources comes at low cost[76]or can even generate savings by reducing dependence on volatile and often expensive resource markets.[77] Beyond financial savings, reducing demand for resources can help mitigate the environmental impact of extraction. Although the environmental impact differs across materials, the bill is substantial not accounting for wider damage to ecosystems:

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[70] The Shift Project. (2025). *La souveraineté par la décarbonation*
[71] T&E. (2025). *State of European Transports 2024*
[72] Shift Project. (2025). *La souveraineté par la décarbonation*
[73] European Parliament. (2020). *Critical Raw Materials Resilience: Charting a Path towards greater security and sustainability*
[74] EIB. (2024). *Navigating Supply Chain Disruptions,*
[75] *Strategic Dependencies and capacities, EU working paper* (2021).
[76] World Economic Forum, *The ROI of transition: the new driver of corporate sustainability agenda*
[77] Real prices of a representative group of resources have increased by more than 300% between 1998 and 2011, and for most resources, population growth and increased demand from emerging countries is expected to drive prices upwards. See Trinomics. (2012). *Mapping resource price: the past and the future*

out of the 75 Gt CO_2-eq projected to be reached by 2060, materials management–extraction, processing, use–are estimated to account for about 50 Gt CO_2-eq.[78] While progress has been made, there is still significant untapped potential from more efficient and productive use of resources. Since 2000, resource productivity in Europe has increased by around 44%.[79] However, the continent's material footprint remains high–at roughly 15 tons per capita[80]–and gains in efficiency have slowed since 2013.[81]

Since resource efficiency has its limits, finding alternative inputs is a parallel undertaking. Finding these alternative sources is innovation intensive. The agricultural sector illustrates this challenge with nitrogen fertilizer supplies strained by geopolitical tensions–prices have tripled since the start of the Russia-Ukraine war and subsequent European sanctions[82]–research is now focused on developing alternative fertilizers. These alternatives could also reduce environmental impact, as synthetic fertilizers are responsible for roughly 3% of global emissions.

Reduced consumption can also be achieved through the circular economy, in particular recycling. This can produce new raw materials as well as alternative sources of inputs with a lesser environmental footprint; secondary materials are estimated to have an impact that is one order magnitude lower than those of primary materials.[83] For example, recycled aluminum consumes 95% less energy than primary production. Greater sovereignty over production is also an outcome of circularity. For example, EcoTitanium, a pioneering French company specializing in recycling aerospace-grade titanium, uses advanced plasma and cold-hearth vacuum furnaces to transform scrap and machining chips into high-quality titanium alloys–consuming four times less energy and reducing CO_2 emissions by around 100,000 tons annually. This process supports a closed-loop titanium economy in Europe and strengthens strategic autonomy for critical industries like aerospace and defense. Although there are physical limits to how many times and what types of products can be recycled, there is still room for improvements in the European Union. For example, municipal waste's estimated maximum potential is a recycling rate of 80%[84], but in 2022 it was far lower than that, at 49%.[85]

Reorienting Europe's industrial base toward strategic sectors

Europe's share of global manufacturing continues to erode. According to Eurostat, the value of sold industrial production declined by 2% in 2024 compared to 2023[86]–the second consecutive year of contraction. Yet even in 2023, Europe was already trailing: its leading manufacturing economy, Germany, accounted for just 5.1% of global manufacturing output, compared to 28.9% for China and 17.2% for the United States.

While a high manufacturing share can reflect industrial strength, it is not a direct measure of overall economic health. The United States, for example, derives less than 10% of its value added from manufacturing–below the European Union's 14% in 2024. Even China, despite its dominance, has seen manufacturing's share of GDP decline from 30% in 2013 to 24.9% in 2024,

[78] OECD. (2019). *Global Material Resources Outlook to 2060*
[79] Eurostat, *Resource productivity statistics*
[80] Eurostat, *Resource productivity statistics*
[81] European Environment Agency. (2018). *Resource efficiency,*
[82] Kee, J., Cardell, L., & Zereyesus, Y. A. (2023, September 18). *Global fertilizer market challenged by Russia's invasion of Ukraine*. U.S. Department of Agriculture, Economic Research Service.
[83] OECD. (2019). *Global Material Resources Outlook to 2060*
[84] European Environment Agency. (2020). *The case for increasing recycling; Estimating the potential for recycling in Europe*
[85] European Environment Agency. (2024). *Waste recycling in Europe*
[86] Eurostat, *Industrial Production Statistics* [accessed on July 30, 2025]

reflecting its ongoing economic transition. Although much has been said about Europe's dependence on China, Europe also supplies 24% of China's concentrated imports[87]– suggesting some mutual leverage – and, according to the OECD, countries like Germany, the UK, France, and Italy have kept import dependency relatively low.[88] Nevertheless, there is a growing recognition that a low share of domestic manufacturing value added can leave an entire economy exposed to trade disruptions. The Covid-19 crisis underscored this risk: Europe's heavy reliance on Chinese face mask production not only led to critical shortages but also had broader geopolitical consequences.[89]

Europe's shrinking share of global manufacturing is both a major concern for sociological and job creation reasons and leaves the region exposed, with heavy reliance on imported intermediate inputs and the concentration of trade dependencies in critical sectors**.** These stem largely from globalization's push toward trade specialization, which has led a handful of countries to dominate key industries. For instance, in 2023, China accounted for 33% of global electronics exports, followed by Taiwan with 12% and South Korea with 8%.[90] This concentration poses a particular risk for Europe, as many of the sectors it relies on are strategically vital: an EIB study highlights electronics as the most critical sector, closely followed by energy.[91] Although some of these trade dependencies are on final goods (as the mask production example highlights), one of the key concerns for Europe is the high share of foreign intermediate inputs in its production: the EU imports 13% to 22% of intermediate inputs used to produces goods that are exported.[92] For example, more than 15% of France's extra-EU imports of intermediate goods came from geopolitically distant countries, and more than 30% for Italy's.[93]

Recognizing this, the European Union has begun to equip itself with a regulatory arsenal designed to reduce structural dependencies and reinforce industrial sovereignty. Central to this effort are policies like the *Net-Zero Industry Act*, part of the *Green Pact*, which aims to localize at least 40% of net-zero technology production in Europe by 2030, and the *Critical Raw Materials Act* (CRMA), which entered into force in May 2024. The CRMA targets the most sensitive supply chain dependencies–137 critical products identified across strategic ecosystems where the EU remains highly reliant on external sources.

But regulations alone are not enough. A pillar of this strategy is the stimulation of both public and private demand for domestically produced, low-carbon goods, along with the deployment of large-scale industrial investment to meet that demand**.** France's recent commitments provide a blueprint: over €50 billion per year in defense procurement (2024–2030), several billion annually for renewable energy tenders, €4 billion for semiconductors and deep tech through *France 2030*, and targeted R&D funds for robotics and advanced manufacturing technologies.

Nonetheless, Europe's industrial base remains inadequately equipped to scale up at the necessary speed and scope. Part of the reason is that Europe's current manufacturing capacity for some key inputs is far lower than competitors who have reached economies of scale, and is hard to scale up: while China produced in 2023 83% of the batteries used worldwide, Europe

[87] OECD. (2025). *Supply Chain Resilience Review*
[88] OECD. (2025). *Supply Chain Resilience Review*
[89] Wang et al. (2020). China's mask diplomacy, *VoxEU*
[90] Titoma. (2024). *Top 10 Electronics Manufacturers by Country*
[91] EIB. (2024). *Navigating Supply Chain Disruptions*
[92] EIB. (2024). *Navigating Supply Chain Disruptions*
[93] Gita Gopinath. (2023). *Europe in a Fragmented W*

only produced 7%[94] , and over half of the lithium-ion battery production planned for Europe in 2030 is at risk of being delayed.[95] This exposes a bottleneck. Meeting the challenge will require not only investment, but a coherent industrial plan–one that proactively structures demand through strategic procurement and reorients supply chains toward sectors deemed essential for resilience, sustainability, and sovereignty.

What is required is industrial redirection**.** For instance, while economists expect the green transition to have a broadly neutral net impact on employment – creating roughly as many jobs as it displaces – this conceals significant labor shifts across sectors.[96] Sectors like recycling, biofuels, and heat pumps, among others, will create jobs, whereas jobs related to the fossil fuels industry will be phased out. These changes will demand substantial investment in reskilling and workforce adaption.[97] Without this alignment, Europe's ambition to lead the green and resilient economy risks stalling in the face of fragmentation and external dependencies. For mid-sized firms and SMEs, this is not just a challenge but a historic opportunity: to position themselves at the core of the new industrial value chains and to thrive in the very sectors where public policy and global demand are converging.

Europe's early leadership in the climate transition has made it the most resilient to disruptions in the shift to a low-carbon economy, reinforcing its position as a post-transition frontrunner. A joint EPO-EIB study shows the EU accounts for 22% of global patents in clean technologies, ahead of Japan (21.1%) and the U.S. (20.2%) However China's share is rising rapidly. Competition is intensifying, and Europe's leadership is at risk, particularly as innovation is constrained by financing; the study notes that median funding amounts are significantly lower in the EU and U.S., especially for smaller firms. Europe can leverage circular and bio-based innovations to enhance competitiveness while advancing climate goals. Scaling plastics made from renewable feedstocks (for instance, sugar beet derivatives) and harmonizing approvals for biotech ingredients in cosmetics would reduce fossil dependence and foster domestic value chains. Accelerating advanced material recovery, particularly chemical recycling for hard-to-recycle streams, alongside IoT-enabled smart waste systems, would raise recycling yields, reduce contamination, and lower logistics costs. In agri-food supply chains, incentivizing regenerative agriculture through outcome-based support, reliable offtake contracts, and robust measurement of soil, biodiversity, and water gains can boost resilience and productivity. These measures should be underpinned by EU-wide standards for traceability and life-cycle assessment, targeted blended finance for first-of-a-kind plants and farm transitions, and strategic industrial clusters that co-locate feedstock, processing, and end markets.

At the microeconomic level, firms can transform their value chains through innovation to enhance resilience and growth

Alongside these broader policy orientations, companies will also have a major role to play: they will need to account for the risks to which they are exposed and invest in sustainability to reduce that exposure. There are already signs that these investments could be profitable, as companies that embed sustainability at their core tend to outperform their peers. For example, sustainable consumer-packaged goods have experienced 55% higher market share

[94] DGE. (2024). Deployment of electromobility: how to develop the European battery supply? *Les Thémas de la DGE*

[95] T&E. (2024). *European made batteries could be 60% less carbon intensive than Chinese – analysis*

[96] CAE. (2023). *Transition énergétique : faut-il craindre pour l'emploi ?*

[97] McDowall and al. (2023). Mapping regional vulnerability in Europe's energy transition: development and application of an indicator to assess declining employment in four carbon-intensive industries, *Climatic Change*

growth than their conventional counterparts[98], highlighting the competitive advantage of sustainability-driven differentiation.

Consumers' preferences are not the only drivers of the economic performance for companies that invest in sustainability. A recent study by PRI and Bain[99] identifies three key drivers of ESG-related value creation: cost reductions, revenue growth (excluding consumer base expansion), and risk mitigation.

This improved performance is largely attributed to the greater resilience and adaptability of companies that actively integrate sustainability into their operations. Below are some of the key factors contributing to this advantage:

Exhibit 2 – Source: Ardabelle Capital interviews and analysis.

Inaction is costly. For businesses, it can affect operating expenses (for example through volatility in the price of a resource), capital expenses (if warehouses are damaged by a natural disaster), revenues (consumers are hit by the shock and temporarily unable to buy, for example), or on the value of assets (if the company is seen as risky).[100] In 2019 already, according to the Carbon Disclosure Project, the 215 biggest global companies reported almost $1 trillion at risk from climate impact[101], and other studies suggest companies have already felt

[98] NYU Stern CSB & Circana. (2023).
[99] PRI, Bain & Company. (2025). *Sustainability Value Creation*
[100] Axa Climate. (2024). *Managing Climate Adaptation: Meeting the Challenge of a Warming World for Business*
[101] CDP. (2019). *World's biggest companies face $1 trillion in climate change risks*

the effects on operations.[102] Mitigation and adaptation alike can significantly reduce these potential losses.

Even if companies fail to account for risks, financial markets are becoming better at pricing risks including climate-related ones that were largely overlooked in the past. One study highlighted the existence of a "carbon premium", suggesting that investors are taking into account the risk associated with high emissions and demanding higher returns.[103] Calls to incorporate sustainability more deeply into financial services are increasing: the PRI and Bain study cited above asserts that, for portfolio companies, "identifying material sustainability topics and key value-driving initiatives aligned with the company's maturity and capabilities is e*ssential* for delivering financial returns." Large companies have the means to induce effective change. Investment in decarbonization or resilience building can involve large upfront costs (in a recent Morgan Stanley survey, 24% of respondents named high investment as one of the top three barriers to delivering on their sustainability strategy[104]). We think that initiatives by large consumer-facing corporates able to drive change through their supply chains can ease financial barriers for the rest of the ecosystem, especially by making sustainable suppliers the most competitive.

Large consumer-facing companies can drive change through their supply chains

For large consumer-facing corporate companies, one of the most effective ways to improve sustainability, financial performance, and resilience is by reducing Scope 3 emissions–those that come from the wider value chain, like suppliers, transportation, product use, and end-of-life disposal. This is becoming increasingly important, not just from a regulatory standpoint, with rules like the EU's CSRD pushing for greater emissions transparency, but also from a business perspective. IKEA (Ingka Group) reduced its total value chain emissions by 30% between 2016 and 2024 through systematic supplier engagement, renewable energy deployment across operations, and circular product design—while simultaneously growing revenue by 24%.[105]These sustainability investments generated direct cost advantages that enabled the company to invest €2.1 billion in price reductions for customers in 2024 alone, demonstrating that decarbonization can strengthen rather than undermine competitive positioning.[106]

Reducing Scope 3 emissions and resilience across the supply chain presents a significant challenge for most companies, nonetheless**.** Unlike Scope 1 and 2 emissions–those from direct operations or purchased energy–Scope 3 emissions originate from upstream and downstream activities in the value chain, where companies often have limited visibility and control. The data is frequently incomplete, inconsistent, or entirely unavailable, making it hard to measure emissions accurately, let alone reduce them. Additionally, companies may lack the leverage or influence to drive change among suppliers or customers, especially when dealing with complex, global supply chains. Despite these challenges, several key strategies have emerged as effective ways to reduce Scope 3 emissions. We outline below the five main

[102] In one study, 57% of companies said events like extreme heat or storms impacted operations during 2024. See, Morgan Stanley, 2025, *Sustainable Signals*

[103] Bolton and Kacperczyk. (2021). Do Investors Care About Carbon Risk? *Journal of Financial Economics*

[104] Morgan Stanley. (2025). *Sustainable Signals*

[105] Ingka Group. (2025). *Annual Summary and Sustainability Report FY24*.

[106] Ingka Group. (2025). *Annual Summary and Sustainability Report FY24*; TriplePundit. (2024). *Ikea Proves Increased Revenue and Sustainability Go Hand-In-Hand*.

actions companies can use to address these indirect emissions and begin building a more resilient, low-carbon value chain.

Strategy 1: Strategic supplier engagement and collaboration *(through capacity building)*

Firms need supplier engagement and collaboration to avoid being left stranded when a shock hits their network of suppliers. Establishing strong, trust-based relationships across the supply chain enables firms to identify solutions collaboratively through open communication. Firms with fewer suppliers tend to be more resilient, because they are better able to foster close relationships with each of them.[107] In 2012, when a fire hit Evonik's plant in Germany, close collaboration between suppliers and customers allowed them to find temporary substitutes for Evonik's cyclododecatriene, a small but necessary component of car production.[108]

Engagement and collaboration are essential for building long-term resilience and advancing sustainable practices. Examples of collaboration along the value chain driving structural change include Schneider Electric's "Zero Carbon Project," which aims to cut the carbon footprint of its 1,000 largest suppliers by 50%, Bel Group's sustainability initiative to protect biodiversity "from farm to fork"[109], and McCain's partnership with potato growers to help them implement regenerative practices.[110]

Strategy 2: A decarbonized procurement strategy (*through green tech and innovation)*

For downstream firms' environmental strategies to ripple up the supply chain, they need to set sustainable standards in their procurement practices. L'Oréal's pledge that 75% of its ingredients will be derived from renewable plant source, abundant materials, of circular process in 2030 effectively reorganizes the upstream market for ingredients, helping traditional suppliers to shift toward another segment of the market and giving a competitive edge to sustainable suppliers.[111] Through procurement strategies, firms can simultaneously gain in resilience and decrease their emissions: Coca-Cola's procurement strategy highlights how efforts to protect biodiversity and promote sustainable sourcing make its supply chain more resilient.[112]

A more common strategy aimed at building resilience through flexibility into production is to diversify sourcing strategies, through reshoring, nearshoring, or more balanced offshoring**.** According to Bain[113], these approaches are gaining momentum: by 2025, 80% of chief operating officers planned to increase their use of nearshoring or reshoring within the next three years, up from 63% in 2022. That said, few companies intend to fully localize supply chains. The dominant model is split shoring–that is, combining local and offshore suppliers. This allows firms to balance resilience with cost-efficiency. Bain estimates that this strategy can boost gross margins by up to 30%. However, reshoring and nearshoring is not always viable. In some cases, global supply is so heavily concentrated in one country that no alternative producer could

[107] G. Khana, N. Morales, N. Pandalai-Nayar. (2022). Supply Chain Resilience : Evidence from Indian Firms. *NBER Working Paper*
[108] P. Truco, A. Nessi. (2020). Resilience strategies for complex supply chains: Evonik industries. *About Resilience*
[109] Groupe Bel, *Notre politique RSE, Biodiversité*
[110] McCain. (2024). McCain's Regenerative Agriculture Framework
[111] L'Oréal. (2025). *L'Oréal for the future roadmap*
[112] T. Babarinde, A. O. Oyebisi, *Examining the Strategic Impact of Procurement on Improving Supply Chain Resilience and Performance: A Case Study of Coca-Cola*
[113] Bain & Company. (2025). *Nearshoring: Overcoming the obstacles*

absorb the reallocated demand. A McKinsey "rearrangement index"[114] assessed the difficulty of diversifying supply away from dominant countries and found that most intermediate goods fall within a manageable range. Yet this conceals significant variation: sectors like electronics face particularly high barriers to supplier diversification.

Strategy 3: Leveraging AI and data

To build a true end-to-end view of the supply chain, advanced data analytics–and increasingly, generative AI–have become essential**.** Visibility is a priority so that firms know where every component is in real time and can identify bottlenecks or risks as they emerge. This level of transparency enables companies to operate more efficiently, reduce waste, and respond rapidly during disruptions. Walmart's swift response during Hurricane Katrina, outperforming FEMA, is often credited to its use of predictive analytics[115].

Generative AI is now poised to revolutionize supply chain data management**.** Visibility software is gaining traction, offering real-time tracking of inventory and shipments while optimizing operations to minimize waste.[116] This is increasingly necessary, as only 30% of firms report visibility bey[117]ond their direct suppliers.[118] Furthermore, data and AI play a critical role in measuring Scope 3 emissions and mapping risks in the supply chain, helping companies improve sustainability, meet regulatory demands and construct business continuity plans. One example of this is the Food and Beverage industry's answer to the European Union's Deforestation Regulation: they have increasingly deployed sustainability measurement platforms using satellite data and artificial intelligence to track the deforestation caused along their supply chain.[119]

Beyond measurement and traceability, some firms are using data and AI to actively reshape sourcing and risk-management decisions.[120] Unilever[121], for example, has deployed advanced analytics and AI-driven forecasting tools across its global supply network to anticipate disruptions, optimize inventory levels, and dynamically rebalance sourcing across suppliers and regions. By combining internal procurement data with external signals such as weather patterns, logistics congestion, and commodity price movements, the company has improved service levels while reducing waste and exposure to supply shocks.

More broadly, data and the tools it enables are becoming a structural differentiator. Virtual twin technology, which integrates vast amounts of information from diverse sources to model and simulate countless scenarios, represents a paradigm shift in supply chain management. By enabling science-based decision-making and transparent collaboration across stakeholders, virtual twins allow companies to understand and optimize their operations at a systems level, testing resilience strategies, sourcing alternatives, and decarbonization pathways before committing physical resources.

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[114] McKinsey Global Institute. (2025). *The great trade rearrangement*

[115] Steven Horwitz. (2029).Walmart to the Rescue – Private Enterprise's Response to Hurricane Katrina. *Independent Review*

[116] Financial Times. (2025). *Companies seek AI solution to help supply chain fragility*

[117] Tech Clarity. (2026). *Measuring the Sustainability Impact of Digital Transformation*

[118] Business Continuity Institute. (2024). *The BCI Supply Chain Resilience Report 2024*

[119] Reuters. (2024). « How AI can help the food sector to meet new deforestation rules

[120] Alicke, K., Azcue, X., & Barriball, E. (2022). *Supply chains: To build resilience, manage proactively*. McKinsey & Company.

[121] Unilever. (2021). *Unilever accelerates digital supply chain transformation*.

This illustrates how data and AI can move supply chains from reactive crisis management toward anticipatory, resilience-oriented decision-making, with direct implications for both cost efficiency and sustainability outcomes.

Strategy 4: Sustainable product design and service *(through green tech and innovation)*

Designing industrial processes with sustainability and resilience at their core is increasingly important. The objective is twofold: to improve efficiency by using fewer resources and to increase flexibility by enabling the use of alternative inputs, thereby reducing reliance on specific suppliers or regions. Many business leaders now cite cost savings as a primary reason why sustainability initiatives are not just ethical, but strategically valuable.[122] More efficient, less resource-intensive processes often translate directly into lower operating costs. For instance, in 2022 Coca-Cola introduced lightweight PET bottles, cutting plastic use by 6,800 tons annually–an innovation that significantly reduced material costs and emissions across their supply chain.[123] Innovation also plays a role in increasing input flexibility. In the cosmetics sector: several brands have developed formulations that incorporate byproducts from other industries–for example, repurposing fruit waste such as kiwi skins from the food industry. This approach not only lowers raw material costs but also adds circularity to product development, turning potential waste into valuable inputs.

Sustainability and resilience do not stop at production**.** They also extend to how products are used and disposed of by consumers–factors captured in Scope 3 emissions. A key consideration is whether the product can be reused, recycled, or recovered after use. This not only reduces the environmental footprint of post-consumer waste but also increases the availability of secondary (recycled) raw materials for future production. In this context, eco-design has become a cornerstone of sustainable product strategy. For instance, Tennant[124], a company that produces cleaning equipment, reported avoiding 75,000 metric tons of CO_2eq thanks to customers using its ecH_2O proprietary technology, which electrically converts tap water into a cleaning solution–eliminating the need for conventional chemical products. This innovation not only reduced emissions and resource use but also generated $1.2 billion in revenue, showing how designing for sustainability can deliver measurable environmental and financial returns.

Strategy 5: Stakeholder engagement *(through governance and collaboration)*

Suppliers are not the only stakeholders to associate with the company's resilience and sustainability journey. This includes employee engagement; for example, Henkel's Laundry & Home's chief supply chain officer Dick Holbach has said that a successful supply chain is also about "the mindset and ability of everyone to quickly sense and react." This goes through strategic hiring practices and formation. Both the SBTi and the MacArthur Foundation highlight the need to mobilize investments towards these initiatives. Competitors and governments can also be associated to wider initiatives: for example, after experiencing once-in-250 years drought in 2014 and 2015 in its Brazilian manufacturing plants, Coca-Cola formed together with

[122] Capgemini Research Institute, 2025, *Driving business value through sustainability*
[123] Coca-Cola. (2024). *We're saving 6,800 tons of plastic per year by introducing new lighter weight necks for carbonated soft drinks bottle*
[124] SBTi. (2018). *Best Practices in Scope 3 Greenhouse Gas Management.*

rival companies such as PepsiCo and AB InBev the "Coalition of Cities for Water"[125]. This initiative to protect or restore local watersheds was supported by local governments.

Larger economic and institutional ecosystems can act as resources and levers for companies to strengthen resilience. A case in point is that of the BITD (*Base Industrielle et Technologique de Défense*), an ecosystem comprising more than 4000 companies and public actors (DGA, CEA, CNES) of the defense sector. Its goal is to secure a complete strategic autonomy of French defense capacities, both in terms of production capacities and technological autonomy, thereby avoiding any critical dependencies on supplies from other countries. In the consumer good sectors, industry-wide initiatives can help overcome the so-called prisoners' dilemma, resolving the issue of why a firm should invest in a supplier's transition when the benefits will also be reaped by its competitors. Industry initiatives can also soften the administrative burden on suppliers; when each company asks its suppliers for different data and assessments to evaluate environmental performance and resilience across the supply chains, it puts suppliers under increased administrative pressure to face these demands. For instance, in the cosmetics industry, initiatives such as the Responsible Beauty Initiative help industry players share EcoVadis assessments of their suppliers.[126]

SMEs can be engines of a green and resilient transformation of supply chains

Change enacted by large downstream corporates drives up the supply chain, creating both pressure and opportunity for smaller players and making sustainability more competitive for them. SMEs need to build resilience**.** They remain highly vulnerable to shocks and often under-equipped to respond during the Covid-19 crisis: the OECD reported that 70% to 80% of SMEs across 32 countries lost between 30% and 50% in revenue.[127] SMEs were on average 12.2 points more severely affected than larger firms.[128] Their fragility is not only economic, but also systemic. Their resilience is often constrained by limited capital buffers, weaker bargaining power in supply chains, and underinvestment in digital or climate adaptation tools.[129] They are vulnerable not just economically, but also in terms of their environmental and social resilience.

These vulnerabilities make targeted support crucial. Our analysis suggests that there is a broad need for financial actors, including private equity funds, to play a more active role in helping SMEs become more resilient. Greater SME resilience–which can be achieved through access to green finance, digital tools, and strategic public procurement–multiplies impact across entire ecosystems.[130] SMEs represent 99% of EU businesses and account for almost half of private sector employment.[131] They are thus determinant for the health of the wider economy. They are especially dominant in industrial supply chains, where they operate as Tier 2 or Tier 3 suppliers. This structural positioning gives them unique leverage: when SMEs adapt, they reshape the supply chains in which they are embedded.

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[125] Cecilia Tornaghi. (2019). In Brazil, Two Corporate Giants, a Drought and an Unexpected Partnership. *Americas Quarterly.*

[126] Responsible Beauty Initiative. (2023). *Responsible Beauty Initiative – Supplier sustainability and EcoVadis sharing framework*

[127] OECD. (2021).*One year of SME and entrepreneurship policy responses to Covid-19 : Lessons learned to "build back better"*

[128] World Bank. (2023). *The resilience of SMEs and large firms in the COVID-19 Pandemic*

[129] McKinsey. (2022). *Beyond financials : Helping small and medium-size enterprises thrive*

[130] OECD, *Greening SMEs*

[131] Eurostat. (2024). *Micro & small businesses make up 99% of enterprises in the EU*

While they face constraints to improving resilience notably through sustainability, SMEs are inherently flexible and adaptive. Their smaller size often allows for faster decision-making, quicker pivots in business models, and closer relationships with customers and suppliers. These characteristics make them ideal laboratories for testing and scaling innovations in sustainable product design, circular economy practices, and local sourcing strategies. Sustainable and resilient SMEs both mitigate risks and become magnets for investment. Impact investors and green bond markets are increasingly seeking firms with transparent sustainability strategies and supply chain traceability. Indeed, investors tend to accept lower yields for green bonds.[132] For SMEs, integrating sustainability is a path to lower financing costs, greater scalability, and stronger market positioning.

As large consumer-facing corporates increase efforts to decrease Scope 3 emissions, their suppliers can position themselves as leaders by tackling their overall emissions (Scope 1, 2 and 3). If Europe is to reinforce the "green arteries" of its industrial base, it must not only regulate or subsidize from the top, it must activate transformation at the level of the value chain's smallest but most dynamic units. When SMEs adapt, they reshape entire ecosystems, acting as "micro-units" of industrial transition.

How concretely can SMEs seize this opportunity? Large corporations are rapidly expanding their Scope 3 emissions programs and asking suppliers to align with decarbonization goals. This opens space for SMEs to position themselves not only as low-risk partners, but as strategic enablers of their clients' environmental performance.

Drawing from different studies, three categories of high-impact levers emerge:

- Understanding the full emissions footprint – including Scope 1, 2, and 3 – and identifying where SMEs fit in larger corporate decarbonization roadmaps.
- Engaging in upstream-downstream collaboration to identify critical vulnerabilities and externalities, particularly at the Tier 2–3 level, and to co-creating transition strategies.
- Adopting low-cost, high-ROI interventions such as energy efficiency, waste reduction, and local sourcing. Some of these interventions can cut emissions up to €20/ton CO_2.[133]

This shift requires support, not only in financing, but in data access, regulatory navigation, and technical assistance. Policymakers and financiers must treat SMEs not as constraints, but as islands of resilience within broader systems, capable of bringing about change both upstream and downstream. The next chapter explores some examples of implementing resilience in selected strategic sectors.

[132] Valérie Chouard, Tristan Jourde. (2024). Green Premium: can firms fund their green projects at a lower cost? *Eco Notepad*

[133] McKinsey. (2009). Impact of the financial crisis on carbon economics

3. How selected sectors are implementing resilience strategies

Economic resilience is not an abstract property of systems but rather the aggregate result of sectoral capacities to anticipate disruption, reorganize production processes, and maintain value creation under constraint. This chapter looks in detail at how various selected sectors are implementing resilience strategies, through the activation by companies of specific operational levers and collective adaptation mechanisms. The sectors we examined–Food and Beverage, Beauty, Luxury and Fashion, Construction and Public Works, and Defense–each have distinct supply chains, environmental footprints, and regulatory dynamics. They provide a relevant analytical field to explore how resilience intertwines with the ecological transition.

The assessment of cost–benefit trade-offs within this transition process necessarily varies across industries: in the Food and Beverage sector, resilience often hinges on relocalization and on securing agricultural inputs, for example, while in Beauty and in Luxury and Fashion, it involves responsible choices in packaging, formulation, and sourcing. In the Construction and Public Works sector, resilience is closely linked to the decarbonization of materials, the circular management of waste, and the electrification of machinery, all of which require coordinated investment across fragmented supplier networks. In Defense, resilience and sustainability converge around energy efficiency, material substitution, and the reduction of operational carbon footprints, particularly in logistics and the deployment of low-emission technologies compatible with strict performance and security requirements.

Beyond their individual specificities, we selected these five sectors to reflect the diversity of the entire value chain: from upstream input-intensive activities such as agriculture (Food and Beverage), to design- and branding-driven industries (Beauty, Luxury and Fashion), to large-scale infrastructure domains relying on complex public-private cooperation (Construction and Public Works), and finally to highly strategic, technologically advanced ecosystems with stringent operational constraints (Defense). Together, they offer a comprehensive lens through which to observe how ecological transition challenges and resilient strategies manifest across all stages of economic production. These sectors were chosen not only for their intrinsic societal value but also for their economic scale and systemic importance: collectively, they represent substantial shares of GDP, employment, and industrial output across Europe. Their transformation is therefore not a niche concern but a macroeconomic imperative, since disruptions in any of these sectors cascade through the broader economy, while their successful adaptation strengthens the entire system's capacity to withstand shocks and sustain long-term prosperity.

A key takeaway from this analysis is that fostering green resilience implies moving beyond the isolated behaviors of individual firms to embrace systemic transformations at the scale of entire value chains and industrial ecosystems. Such a shift requires rethinking the structural coordination mechanisms that underpin competitiveness and sustainability alike. Advancing toward a resilient economy entails both differentiating financial support in favor of already “green” actors and enabling the progressive greening of suppliers and partners that have yet to align with sustainability standards. Among the potential instruments supporting this transformation, the integration of carbon accounting within traditional financial accounting

frameworks stands out as a key enabler, making environmental externalities measurable, comparable, and governable.

Understanding these sectoral dynamics is a prerequisite to interpreting the broader macroeconomic trajectories of resilience and to envisioning how the European economy might reconcile robustness, competitiveness, and ecological alignment. Practically, across industries and continents, we consider that resilience initiatives implemented in some of the strategies exposed in Exhibit 3 unfold into six operational functions and one prerequisite (risk mapping and management). These are the foundations upon which resilient enterprises are built.

The seven levers for building resilience at company level

Exhibit 3 – Source: Ardabelle Capital interviews and analysis.

Risk mapping and management have emerged as a strategic first step, enabling companies to prioritize their focus on areas where they can deliver genuine positive impact and exercise meaningful influence.

Exhibit 4 below synthesizes examples of the main operational levers available to strengthen resilience and accelerate the sustainable transition across five key industries: Food & Beverage, Luxury and Fashion, Beauty, Construction and Public Works and Defense, beyond risk mapping. It illustrates how common strategic objectives–such as risk reduction, decarbonization, traceability, and supply-chain robustness–translate into distinct, sector-specific actions depending on production structures, regulatory constraints, and supplier ecosystems. By mapping these levers side by side, the table highlights both cross-cutting

mechanisms and industry-specific pathways, providing a practical framework for companies and policymakers to identify high-impact interventions tailored to each sector's operational realities.

Operational levers across the five focus industries

Lever Category	Operational Levers	Food and Beverage	Beauty	Luxury and Fashion	Defense	Construction , Public Works
1. Transition Financing	Direct Incentives	Income Accelerators	Co-investment Platforms	Circular materials Investments	Matched funding	Low-carbon procurement fund
	Risk Sharing / Insurance	Dairy weather insurance	—	—	Advanced payment schemes for SMEs	—
	Blended Finance / Forward Contracts	Commodities Forwards	—	—	—	Investment facilities
	Sustainability-linked Loans	—	Specialized Loans	Sustainability loans	—	Growth Financing
	Micro-grants for SMEs	—	—	Micro-grants for ateliers	—	Supplier equipment/machinery grants
2. Data and Traceability	Digital Traceability	Food Trust Consortium	Consortium	Blockchain Consortium	Data traceability	Digital tracking
	Supplier Portals	Supplier portals	—	—	ESG portals	Supplier qualification portals
	Footprinting & LCA	—	SPICE environmental scoring	Gucci Scrap-less environmental tracking	—	Eiffage carbon/materials footprinting
	Compliance & Auditing	ESG audits	—	ESG audits	—	ESG + safety audits
	Reporting Frameworks	—	EcoBeautyScore consortium	—	—	EPDs (Environmental Product Declarations)
3. Capacity Building	Supplier Training	Training Plans	Training Plans	Training Plans	Training Plans	Training Plans
	Resource Stewardship	Water stewardship	—	—	—	—
	Innovation Partnerships	—	—	New materials production – Research Partnerships	New materials production – Research Partnerships	New materials production – Research Partnerships
	Eco-design Programs	—	—	Eco-design initiatives	—	Low-carbon designs
	Social Empowerment	—	Women Support Initiatives	—	—	—
4. Green Tech. & Innovation	Material Substitution	Plant-based ingredients	Bio-based materials	Bio-based materials	Lightweight composite components	Low-carbon cement
	Green Packaging Innovation	Edible coating	Eco-design packaging standards	—	—	Circular concrete packaging pilots
	Advanced Recycling	—	Carbios enzymatic PET recycling	—	—	CDW (construction waste) recycling – ECOCycle
	Sustainable Infrastructure	Solar cold rooms	—	Solar-powered workshops	Energy-efficient shipyards	Electrified machinery
	Process & Logistics Efficiency	Responsible farming, drone fertilizing	—	Modular production systems	Additive manufacturing	Logistics waste reduction initiatives
5. Waste Management	Retail Waste Reduction	Dynamic pricing	—	—	—	—
	Upcycling & By-product Valorization	Upcycled ingredients	Upcycled ingredients	Upcycled materials	Closed-loop aluminum	Upcycled materials
	Closed-loop Systems	—	Circular water systems	Cloths take-back	Component remanufacturing	Recycled aggregates
	Supply Chain Efficiency	—	—	—	Remanufacturing frameworks	On-site sorting and reuse
	Community Engagement	Community cooperatives	—	Community cooperatives	—	Construction waste programs
6. Governance & Collaboration	Long-term Partnerships	Mars multi-year farmer partnerships	—	—	—	SME partnerships
	Standards & Certifications	Rainforest Alliance, Fairtrade	ISO 16128, RSPO	RJC / GOTS / LWG	NATO procurement standards	ISO 14001 / LEED
	Supplier Inclusion Policies	Local sourcing policies	Ethical Sourcing Charter	Supplier inclusion scorecards	SME participation rules	Social procurement clauses
	Transparency & Reporting	Responsible sourcing reporting	Sustainability reporting	Environmental P&L	Defense procurement transparency audits	CSRD mandatory reporting

Exhibit 4 – Source: Ardabelle Capital interviews and analysis.

Within this section, two sectors (Food and Beverage, and Luxury and Fashion) are examined through in-depth case studies, while analyses of the remaining sectors are provided in the appendix.

Food and Beverage

Overview of risks and materiality

The Food and Beverage (F&B) industry is one of the largest consumer sectors globally, comprising agricultural producers, processors, manufacturers, distributors, and retailers. The industry faces diverse risks including product safety, regulatory compliance, supply chain disruptions, consumer complaints, litigation, and reputational damage. F&B products are unique in being biologically active, perishable, and nutritionally essential. These features amplify both operational fragility and public trust exposure, making sustainability inseparable from resilience.

Taken together, the F&B industry's vulnerabilities converge on the inseparability of sustainability and resilience. Agricultural inputs are increasingly volatile under climate stress; deforestation-driven commodities pose regulatory and reputational risks; and the cold chain represents a structural tension between safety, waste prevention, and decarbonization. At the same time, intentional food fraud underscores the centrality of trust and traceability, while inconsistent Scope 3 disclosure hampers investors' ability to assess exposure. Academic

evidence consistently underscores the upstream dominance of these risks. As Rojas-Reyes et al. (2024) conclude, climate, biological and logistical shocks are the most frequent disruptors of food supply chains, and these shocks are projected to intensify under climate change.[134] Meanwhile, Spink and Moyer (2017) highlight that food fraud is not a food safety issue per se, but a supply chain vulnerability that can have public health consequences[135], demonstrating how reputational and operational risks are entangled.

This interdependence of supply chain fragility, emissions intensity, and reputational exposure implies that environmental and social issues should not be treated as externalities. As Schulman et al. (2021) emphasize, improving Scope 3 disclosure and supplier engagement is not only a climate imperative but a financial necessity for food companies navigating volatile commodity markets.[136] Similarly, Flammini et al. (2024) argue that cold-chain expansion without decarbonization would lock in a new source of emissions growth in the food system[137], showing how operational decisions carry long-term strategic consequences.

The lesson for the F&B sector is that building resilience requires enabling upstream suppliers – especially SMEs – to decarbonize and adapt, embedding life-cycle assessment in product design, and integrating traceability systems to mitigate both fraud and deforestation exposure. In short, sustainability is no longer merely an ethical or compliance concern but a strategic lever for risk management and value creation.

Food safety and fraud

Food safety remains the most immediate risk. Recalls due to contamination or mislabeling can have severe financial and reputational effects. Beyond accidental contamination, intentional adulteration – or food fraud – is an increasingly recognized systemic threat. As Spink and Moyer (2011) note, "food fraud is a collective term used to encompass the deliberate and intentional substitution, addition, tampering, or misrepresentation of food... for economic gain."[138] In a later study, they stress that food fraud is not a food safety issue per se, but a supply chain vulnerability that can have public health consequences. This distinction is critical: fraud requires different governance mechanisms, detection technologies, and supplier oversight than conventional food safety.

Climate, deforestation, and land-use risks

The agricultural base of the F&B industry exposes it directly to climate volatility. Extreme weather events including droughts, floods, and heatwaves disrupt harvests and cause cascading effects across supply chains. Climate change and extreme weather events weaken food supply chains, highlighting the need to expand resilience-building efforts across the entire supply chain and multiple forms of climatic variability.[139] These shocks translate into price

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[134] Rojas-Reyes, J., Rivera-Cadavid, L., & Peña-Orozco, D. L. (2024). Disruptions in the food supply chain: A literature review. *Heliyon*

[135] Spink, J., & Moyer, D. C. (2011). *Defining the public health threat of food fraud*. Journal of Food Science

[136] Schulman, D. J., Bateman, A. H., & Greene, S. E. (2021). Supply chains (Scope 3) toward sustainable food systems: An analysis of food & beverage processing corporate greenhouse gas emissions disclosure. *Cleaner Production Letters*

[137] Flammini, A., Adzmir, H., Pattison, R., Karl, K., Allouche, Y., & Tubiello, F. N. (2024). Greenhouse Gas Emissions from Cold Chains in Agrifood Systems. *Sustainability*

[138] Spink, J., & Moyer, D. C. (2011). *Defining the public health threat of food fraud*. Journal of Food Science, 76(9), R157–R163.

[139] Tchonkouang, R. D., Onyeaka, H., & Nkoutchou, H. (2024). *Assessing the vulnerability of food supply chains to climate change-induced disruptions*. *Science of the Total Environment*

volatility. According to Eurostat, in January 2024 olive oil prices in the European Union were on average 50% higher than a year earlier. The late-2023 inflation rate was even higher, monthly year-on-year price increases of up to 51% in November**,** and even higher in certain countries like Portugal (+69%), Greece (+67%), and Spain (+63%).[140] Commodity-driven deforestation is one of the most reputationally and regulatorily salient risks for the sector. Curtis et al. (2018) conclude that commodity production was the dominant driver of deforestation, responsible for 27% of global forest disturbance between 2001 and 2015.[141] Soy, beef, palm oil, and cocoa are all staples of F&B supply chains, and each is linked to high deforestation footprints, concentrated sourcing regions, and labor rights controversies. Regulatory responses such as the EU Deforestation Regulation make non-compliant sourcing a direct financial liability.

Another critical factor is the role of pesticides and fertilizers in amplifying both environmental vulnerability and supply-chain risk. Climate change tends to exacerbate pest pressures, reduce crop resilience, and alter pest life cycles, which make farmers increasingly reliant on synthetic agrochemicals.[142] Climate-driven shifts in precipitation, temperature, and plant stress result in higher pesticide use, increasing chemical loads in ecosystems and undermining long-term resilience. [143] This creates a feedback loop: intensifying pesticide use contributes to greenhouse gas emissions (via energy-intensive manufacture, transport, and application) and ecological degradation, which in turn weakens the natural buffers of agroecosystems such as soil health and predator populations.[144] In this way, pesticide and fertilizers dynamics represent a systemic risk factor for the F&B industry's supply chain, not only through direct contamination or regulation, but as an amplifier of climate vulnerability.

In the F&B sector, most greenhouse gas emissions occur in Scope 3, which covers the entire value chain outside the company's direct operations. These emissions stem primarily from upstream activities, such as agriculture and raw material production, and downstream activities, including product distribution, consumption, and end-of-life disposal**.** Compared to Scope 1 (direct emissions from owned operations) and Scope 2 (indirect emissions from purchased energy), Scope 3 typically accounts for over 90% of total emissions for major companies, highlighting the critical importance of engaging suppliers, improving sourcing practices, and considering the full lifecycle of products to achieve meaningful reductions in the sector's overall carbon footprint.

[140] *Eurostat*. European Commission, (2024).
[141] Curtis, P. G., Slay, C. M., Harris, N. L., Tyukavina, A., & Hansen, M. C. (2018). Classifying drivers of global forest loss. *Science, 361*(6407), 1108–1111.
[142] Martínez-Megías, A., Hernández, R., & López, F. (2023). Climate change and pest management: Implications for crop protection strategies. *Science of the Total Environment, 872*, 162955.
[143] Tudi, M., Daniel, O., Wang, L., & Ali, M. (2021). Climate change and pesticide use: Emerging risks and adaptive strategies in agriculture. *Frontiers in Sustainable Food Systems, 5*, 643210.
[144] PAN (Pesticide Action Network). (2023). *Pesticides and the climate crisis: Impacts and solutions*.

Structure of total emissions for 6 major actors of the F&B industry

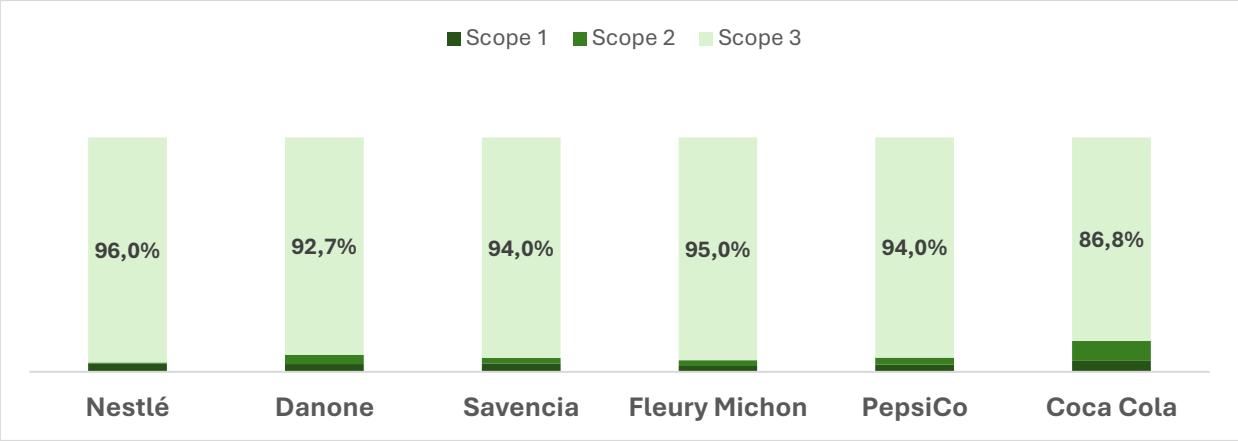

Exhibit 5 – Source: Ardabelle Capital analysis, based on the 2024 Sustainability or Integrated Reports of all 6 companies

Farming and logistics: Cold chain dependence, packaging, and circularity

The F&B sector's emissions are overwhelmingly upstream. Scope 3 emissions constitute the majority of total emissions in the food processing industry, yet disclosure rates remain low and inconsistent.[145] Farming, fertilizer use, livestock enteric emissions, and energy-intensive ingredient processing dominate the footprint, mirroring cosmetics where ingredients and packaging account for most Scope 3 emissions. For both industries, this means supplier engagement – particularly among SMEs – is the central lever for decarbonization.

F&B is structurally dependent on refrigeration. Cold chains preserve safety and reduce waste, but they also increase energy use and emissions. Flammini et al. (2024)[146] estimate that the global agrifood cold chain emitted 1.28 $GtCO_2e$ in 2019, representing about 19% of total food system emissions. This figure highlights the trade-off: refrigeration prevents food waste (itself a 3–4 $GtCO_2e$ problem globally) yet locks in additional emissions if not decarbonized. As the authors argue, cold-chain expansion without decarbonization would lock in a new source of emissions growth in the food system.

Packaging challenges are similar across consumer goods. Substitution–plastic to glass or aluminum–risks "impact shifting" if life-cycle emissions increase due to weight or energy intensity. As with cosmetics, Extended Producer Responsibility schemes in the EU and North America will increase costs for non-circular packaging. Yet packaging remains a reputationally visible issue, often prioritized in sustainability strategies because it is consumer-facing.

Operational levers and industry practices

Agricultural production, ingredient sourcing, and logistics account for most of the environmental and social exposure, much of which lies outside the direct operational control of large brands. This creates a paradox: multinational companies are held accountable by regulators, investors, and consumers for risks they do not directly manage. SMEs including

[145] Schulman, D. J., Bateman, A. H., & Greene, S. E. (2021). Supply chains (Scope 3) toward sustainable food systems: An analysis of food & beverage processing corporate greenhouse gas emissions disclosure. *Cleaner Production Letters*

[146] Flammini, A., Adzmir, H., Pattison, R., Karl, K., Allouche, Y., & Tubiello, F. N. (2024). Greenhouse gas emissions from cold chains in agrifood systems. *Sustainability, 16*(21), 9184.

farmers, cooperatives, processors, and packaging suppliers become the operational fulcrum of resilience and decarbonization.

Financing Sustainable Transitions

In developed countries, financing constraints persist for SMEs despite more mature capital markets, particularly for investments that deliver long-term sustainability benefits but limited short-term returns. French food SMEs are increasingly supported through blended finance, bank partnerships, and public-private instruments that de-risk green investments. For example, Jean Hénaff, a family-owned pork processor in Brittany, has financed its transition toward antibiotic-free supply chains, animal-welfare upgrades, and low-carbon processing through a mix of long-term bank loans, regional public guarantees, and sustainability-linked financing tied to environmental performance indicators[147]. At the system level, public development banks such as BpiFrance play a catalytic role by offering concessional loans and guarantees for agri-food SMEs adopting low-carbon and digital compliance technologies, crowding in private finance while reducing balance-sheet risk for smaller actors.[148]

A barrier for SMEs is the cost of adopting sustainable practices. Regenerative agriculture, renewable-powered cold storage, and traceability technologies all require significant upfront capital, yet SMEs often lack access to affordable credit, especially in developing countries. New financing instruments are emerging to close this gap. Nestlé's Income Accelerator Program[149] in Côte d'Ivoire and Ghana has reached 10,000 cocoa-farming families and aims to scale to 160,000 by 2030, combining direct cash incentives with training and inputs. Participating households saw their annual income rise by 15-20%, while Nestlé simultaneously secured more reliable supply and improved compliance with child-labor and deforestation standards.

Insurance and risk-pooling mechanisms also help. Spain's Agroseguro system, a public-private coinsurance pool of seventeen insurance companies, is one of the most advanced agricultural insurance frameworks in Europe. Covering agricultural, livestock, forestry, and aquaculture production against most climate risks, the system insured production valued at €16.7 billion in 2023, with public subsidies covering nearly 50% of total insurance costs. In 2023, Agroseguro processed 178,000 agricultural claimable events and paid out €1.24 billion in compensation, a 56% increase from 2022, reflecting the growing impact of climate change on European farming. The system's long track record — operational since 1978 — demonstrates that structured risk-sharing between governments, insurers, and farmers can stabilize agricultural income even under escalating climate volatility.[150] In Northern Europe, Arla Foods' FarmAhead Incentive program offers a compelling model. The dairy cooperative links the milk price paid to each of its 9,900 farmer owners across seven European countries to their measurable sustainability performance, rewarding actions on feed efficiency, manure handling, renewable energy, and biodiversity. In 2023, Arla distributed approximately €300 million in its first sustainability incentive payout and expects to pay a cumulative €2.2 billion to farmers by 2030. Farmers using Arla's Climate Check tool have reduced CO_2e emissions per kilogram of milk by 13% since 2015, with top performers achieving reductions of up to 4% annually.[151] These blended incentive models distribute transition costs more evenly across the value chain and demonstrate that climate finance must reach the farm level if Scope 3 targets are to be met.

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[147] Hénaff, J. (2022). *Rapport RSE et performance durable*. Jean Hénaff Corporate Publication

[148] Bpifrance. (2023). *Financer la transition écologique des PME agroalimentaires*. Bpifrance Report

[149] Nestlé. (2023). *Income Accelerator Program: Progress Report* (Test-at-Scale). Kit Royal Tropical Institute.

[150] Agroseguro. (2024). *Annual Report 2023*.

[151] Arla Foods. (2022). *Climate Check Report 2022*.

Data, measurement, and compliance

Even when capital is available, SMEs face structural barriers in monitoring and disclosure. Life-cycle assessment, Scope 3 carbon accounting, and compliance with deforestation-free regulations demand significant data collection and verification capacity that most small actors lack. Large corporates are beginning to invest in shared digital infrastructures. Walmart's partnership with IBM[152] Food Trust reduced the time required to trace mangoes from farm to shelf from 7 days to 2.2 seconds, radically lowering the cost of recalls and improving fraud detection. Nestlé[153] integrated the same blockchain into its Zoégas coffee line, providing consumers with QR code access to farm-level sourcing data.

Fraud prevention is a central motivation. The American-based Grocery Manufacturers Association[154] estimates that food fraud costs the industry $10–15 billion annually in the USA, with recalls averaging $10 million per incident. By combining blockchain traceability with analytical testing (DNA barcoding for fish, isotope analysis for honey, spectrometry for olive oil), companies reduce both financial exposure and reputational risk. Carrefour's **"**Act for Food"[155] program, for example, integrates QR-based traceability with laboratory spot checks, enabling French consumers to verify origin and quality of organic products in-store. For SMEs, these shared systems remove duplicative compliance burdens while protecting them against fraud-induced exclusion from supply chains.

Artificial intelligence is increasingly embedded in data, measurement, and compliance infrastructures in the F&B sector, lowering monitoring costs and strengthening operational resilience across complex supply chains. Unilever integrates AI-driven data validation, automated outlier detection, and supplier risk scoring into its SAP-based global sustainability platform, covering more than 56,000 suppliers, to standardize Scope 3 emissions reporting, reduce audit duplication, and improve compliance with evolving environmental and human-rights regulations[156]. These AI-supported corporate systems function as shared digital infrastructures that SMEs can access indirectly, reducing structural barriers to compliance while strengthening fraud prevention, regulatory readiness, and supply-chain resilience.

Knowledge and capacity building

Finance and data infrastructures are insufficient without parallel investments in human capital. Many companies operate in contexts where regenerative practices, efficient logistics, or packaging alternatives are poorly disseminated. Capacity-building therefore becomes a lever for resilience.

Barilla's Sustainable Farming program, launched in Italy in 2010, supports over 9,000 farms across Italian macro-regions (Emilia Romagna, Tuscany, Puglia, Veneto, and others), offering training in crop rotation, precision fertilization, and integrated pest management through its "Handbook for the Sustainable Cultivation of Quality Durum Wheat" and the *granoduro.net* decision support system. Independent evaluations have shown that participating farms achieved up to 20% higher yields, up to 30% lower production costs, and up to 35% lower

[152] Kamath, R. (2018). *Food traceability on blockchain: Walmart's pork and mango pilots with IBM*. The Journal of The British Blockchain Association

[153] Nestlé. (2020, April 6). *Nestlé expands blockchain to Zoégas coffee brand*.

[154] FSNS. (2020). *An Update On Food Fraud*

[155] Carrefour. (2018, March 6). *Carrefour launches Europe's first food blockchain*

[156] Unilever. (2023). Enhancing transparency and trust across our value chain. Unilever Sustainability Progress Report.

greenhouse gas emissions compared to conventional systems. Barilla complements this with multi-year cultivation contracts guaranteeing farmers premiums of on average 25% above standard market contracts, securing both supply quality and farmer income stability.[157] Heineken's water stewardship initiatives in Spain combine ecosystem restoration with infrastructure co-financing. Through its "Every Drop" water balancing program, Heineken has invested in three major water compensation projects, including the Doñana wetland restoration in southern Spain, restoring over 1 billion liters of water annually to one of Europe's most important — and water-stressed — ecosystems. Across its Spanish operations, Heineken has compensated a total of 1.4 billion liters of water, the equivalent of 560 Olympic swimming pools, while simultaneously reducing its brewery water usage by nearly one-third since 2008. These measures strengthen both watershed health and supply resilience for the brewer, in a country facing the highest level of water stress in Europe.[158]

Supplier academies are also scaling. Nestlé's Nescafé Plan 2030[159] includes training for farmers**.** In 2023, the program reached over 277,000 coffee farmers across 27 countries, providing training in regenerative practices such as intercropping, optimized fertilizer use, and agroforestry. These efforts have led to a 15–30% reduction in greenhouse gas emissions per kilogram of coffee and a 5–25% increase in yields per hectare in regions like Vietnam, Honduras, and India in regenerative techniques, with pilots in Vietnam showing that intercropping and optimized fertilizer use can lower emissions per kg of coffee by 15–30% while improving net farmer profitability.

Additionally, there are many similar examples across the industry. General Mills (USA) runs farmer-facing regenerative programs in key U.S. "supply sheds," and has a structured 6-month program supporting "next generation" farmers transitioning to regenerative practices[160]. Danone (France / Europe) has multiple regenerative-ag projects explicitly combining audits with training and technical support for farmers. It also maintains a Regenerative Agriculture Knowledge Center aimed at farmers, advisors, and field technicians.[161] Unilever and PepsiCo[162] have joined a new collaborative initiative called "STEP up for Agriculture" that aims to scale regenerative farming practices by equipping farmer-facing organizations with tools, training, funding, and measurement systems to help farmers adopt these methods and build more resilient supply chains. The program includes annual in-person workshops and support to help farmers implement regenerative practices and helps both companies advance their own sustainability targets. PepsiCo's goal to transition 10 million acres and Unilever's goal to reach 1 million hectares by 2030. McCain Foods commits to rolling out regenerative agriculture[163] across 100% of its global potato acreage by 2030, supported by a clear framework defining principles, priority practices, and measurable progress thresholds.

These examples illustrate how capacity-building, when embedded in long-term sourcing programs, creates measurable value both for SMEs and for the corporations that rely on them.

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[157] Barilla Group. (2017). *10 Barilla sustainability stories*

[158] Heineken. (2019). *HEINEKEN announces "Every Drop" water ambition for 2030*.

[159] Nestlé. (2024). *Nescafé Plan 2030 progress report 2023: Regenerative agriculture*.

[160] https://www.generalmills.com/how-we-make-it/healthier-planet/environmental-impact/regenerative-agriculture/for-farmers?utm_source=chatgpt.com

[161] https://ecosystem.danone.com/knowledge/

[162] https://www.foodnavigator.com/Article/2025/09/19/unilever-pepsico-join-regenerative-agriculture-initiative/

[163] https://www.mccain.com/media/4031/mccain-foods-regenerative-agriculture.pdf?utm_source=chatgpt.com

Green technology and innovation

Technological innovation provides some of the clearest pathways to decarbonization and resilience. The most promising levers fall into product innovation, packaging innovation, sourcing, agricultural innovation, and process and logistics efficiency. Product innovation is illustrated by La Belle-Iloise[164], a mid-sized French fish canning company. Its 100% plant-based seafood alternatives, using lentils and seaweed, are projected to generate 20% of total revenue in coming years, diversifying income while reducing reliance on marine resources. On a global scale, Unilever [165]reported that its "sustainable living brands" (e.g., Knorr, Hellmann's) grew 69% faster than the rest of its portfolio in 2019 and contributed 75% of total growth, showing how product innovation tied to sustainability can generate above-market returns. Packaging innovation is exemplified by Apeel Sciences[166], whose edible coatings doubled the shelf life of avocados and citrus. By 2023, Apeel estimated it had prevented the waste of 166 million units of produce, conserved 1.8 billion gallons of water, and avoided approximatively 29,000 tons of CO_2 emissions. Meanwhile, Unilever's former tea division (Lipton)[167] shifted from plastic to fully biodegradable tea bags, cutting 1,000 tons of plastic annually, while replacing plastic closures with corn-based biopolymers. At the same time, many existing business models must be questioned and adapted to make space for innovative solutions and to phase out firms whose profits rely heavily on negative externalities.[168]

Sourcing and agricultural innovation remain the largest lever for emission reduction in the F&B sector. Tea is a particularly illustrative case. Among major beverages, tea has one of the lowest energy and carbon footprints: brewing a cup of tea generates roughly 0.05 kg CO_2 per liter, compared to 0.5 kg for bottled water and 0.6 kg for coffee.[169] Yet while processing emissions are modest, the majority of tea's footprint, up to 75% of total lifecycle emissions, comes from upstream agricultural inputs, especially synthetic fertilizers and pesticides. Addressing this issue is central to decarbonization strategies. Lipton Teas & Infusions has positioned East Africa – particularly Kenya, Rwanda, and Tanzania – as the cornerstone of its agricultural innovation strategy. The region's climatic conditions are naturally favorable to tea cultivation: high altitude, abundant rainfall during the growing season, and long periods of sunshine. These agro-ecological advantages mean that tea varieties grown in East Africa are inherently less vulnerable to fungal diseases and insect infestations than those grown in more humid or low-lying regions of Asia. Coupled with the selection of drought- and pest-resistant clones, this has enabled Lipton to progressively eliminate synthetic pesticides. As of 2023, its Kenyan and Rwandan estates are 100% pesticide-free, with Tanzanian estates expected to follow by 2025, thanks to integrated pest management (IPM) approaches and biological controls. In parallel, Lipton has invested in drone-assisted precision fertilization, targeting applications of organic manure only where needed. Early results show fertilizer use is reduced by up to 20% while maintaining stable yields. This precision approach not only lowers emissions from fertilizer production and application but also reduces runoff into local ecosystems. A second innovation, the IoTEA™ digital platform (developed with Cranfield University), integrates weather, soil, and plant growth data to optimize harvesting schedules and input application. Lipton projects that such tools could lift yields by 50% over the next decade, even as chemical inputs decline.

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[164] *Les Echos*. (2025, 9 juillet)
[165] Unilever. (2019, June 11). *Unilever's purpose-led, Sustainable Living Brands outperform*.
[166] Apeel Sciences. (2023). *Apeel impact report 2023*
[167] Unilever. (2021, March 15). Four new ways we're rethinking our plastic packaging
[168] Velbeln Insitutue. (2026). Expert Interview
[169] Lipton Teas and Infusions. (2024). *LIPTON Teas and Infusions Sustainability Report 2024*.

This example shows how sourcing decisions can achieve double dividends: East African estates provide both a natural comparative advantage (pesticide-free production) and a technological testbed for scaling regenerative practices across global supply chains. Finally, process and logistics innovations address waste and emissions beyond the farm. In Europe, Carrier Transicold's Vector eCool, the world's first fully autonomous, all-electric engineless trailer refrigeration unit, is now operating across 10 European countries including France, Germany, the Netherlands, and the UK. A multi-year performance evaluation by a major UK customer across a fleet of more than 2,000 Carrier Transicold units demonstrated close to a 50% reduction in carbon emissions, saving approximately 1,118 metric tonnes of CO_2 over four years. Carrier Transicold's latest innovations, combining low-GWP refrigerants with biofuel compatibility, can achieve a total reduction of up to 73% in CO_2 emissions per year of use, while meeting urban noise regulations — addressing the cold chain's decarbonization challenge at the logistics level.[170]

Waste management and resource efficiency

Reducing food loss across supply chains is both an environmental and an economic lever. Tesco's "Perfectly Imperfect"[171] program markets cosmetically imperfect produce, cutting in-store fruit and vegetable waste by up to 30%**.** Since its launch in 2016, the initiative has saved over 68 million packs of produce from going to waste by offering cosmetically imperfect items at reduced prices. Carrefour[172] has tested AI-powered dynamic pricing algorithms for perishables in Spain, reducing daily waste volumes by 20**%.** At the processing stage, AB InBev[173] has developed "EverGrain," a high-protein flour made from spent barley, now commercialized with food manufacturers. This by-product valorization not only diverts waste but is expected to generate a new revenue stream worth hundreds of millions annually if scaled across AB InBev's global footprint. Logistics optimization offers a further efficiency lever: Dassault Systèmes deployed route planning solutions for a major grocery retailer, avoiding 528 km of delivery vehicle travel per day and 7.6 tCO2e of daily emissions, illustrating how digital tools can compress resource waste across last-mile operations.[174]

Governance and collaboration models

Finally, systemic resilience depends on governance models that go beyond transactional compliance. Traditional auditing imposes costs on SMEs without addressing structural barriers.

In response, leading firms are shifting towards relational governance. Mars[175] has moved from spot-buying cocoa to multi-year sourcing agreements, ensuring price stability for farmers while requiring progress on deforestation-free commitments. The company reports that its long-term cocoa contracts reduce supply volatility, a key factor in stabilizing its gross margins. FrieslandCampina, the Dutch dairy cooperative, operates the Foqus planet quality and sustainability program across its nearly 10,000 member farms in the Netherlands, Belgium,

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[170] Carrier Transicold. (2021). *Carrier Transicold continues to expand electric transport refrigeration across Europe*.
[171] Tesco. (2024). *Food Waste Report 2024*.
[172] Carrefour. (2023). *Universal Registration Document 2023*
[173] Belt, G. (2023, May 18). From beer to bars: How AB InBev's EverGrain finds new uses for spent barley. *Food Dive*
[174] Dassault Systemes. (2025). *From store to fridge: how one industry leader is mitigating grocery delivery emissions*
[175] Mars Incorporated. (2023). *Mars accelerates progress towards 100% responsibly sourced cocoa*

Germany, and four other Northern European countries. The program rewards farmers with financial premiums based on measurable results across nine indicators, including greenhouse gas emissions, biodiversity, pasture grazing, and animal welfare. In 2023, FrieslandCampina paid out over €245 million in sustainability premiums — of which €190 million came through Foqus planet — enabling an average premium of €2.63 per 100 kg of milk. Developed in collaboration with WWF Netherlands and Rabobank, the program's Biodiversity Monitor provides farm-level ecological data, while over 5,000 farmers have participated in "Winning with Climate and Nature" workshops.[176]

Some companies go further, building pre-competitive coalitions that pool knowledge across rival firms. In February 2026, Pernod Ricard joined the Advisory Board of the World Living Soils Forum alongside Moët Hennessy (LVMH), Nestlé & Nespresso, and the BPCE Group (with Natixis CIB and Mirova), creating a cross-sectoral governance body dedicated to scaling soil regeneration practices across agricultural and viticultural supply chains.[177] Founded by Moët Hennessy in 2022 and co-organized with ChangeNOW, the Forum brings together scientists, farmers, NGOs, and corporates to develop measurable strategies for regenerative agriculture — deliberately transcending competitive and sectoral boundaries. For Pernod Ricard, which has deployed regenerative agriculture programs across its priority terroirs since 2019, the coalition offers a vehicle to harmonize metrics and share operational feedback, converting what would otherwise remain firm-level pilot projects into an industry-wide transition pathway.

These approaches reflect a fundamental shift: from policing suppliers to enabling them. By embedding co-investment, shared monitoring, and long-term relationships, multinational companies can convert compliance costs into resilience dividends.

Operational levers and industry practices in the F&B Sector

Category	Operational Lever / Practice	Description	Example(s)
1. Financing Sustainable Transitions	Direct cash incentives & input support	Financial support to SMEs for sustainable practices	Nestlé Income Accelerator Program (Côte d'Ivoire, Ghana)
	Cooperative insurance & risk-pooling	Reduce SME exposure to weather/climate risk	Agroseguro public-private insurance system (Spain)
	Blended finance & forward contracts	Shared investment in sustainable transitions	Arla Foods FarmAhead Incentive (Norther Europe)
2. Data, Measurement & Compliance	Digital traceability systems	Track products from farm to shelf, improve compliance & fraud prevention	Walmart + IBM Food Trust (mangoes) (USA); Nestlé blockchain for Zoégas coffee (Colombia & Brazil)

[176] FrieslandCampina. (2024). *FrieslandCampina dairy farmers receive over €245 million in sustainability premiums*

[177] World Living Soils Forum. (2026, February 20). World Living Soils Forum — June 3–4, 2026 at LUMA Arles: New Alliances and Themes to Drive Soil Regeneration

	Supplier sustainability portals	Standardize Scope 3 reporting and audits	Unilever SAP supplier portal (56,000+ suppliers) (UK / Netherlands)
	Analytical testing & fraud detection	DNA barcoding, isotope analysis, spectrometry	Carrefour "Act for Food" program (France)
	AI-tools development	Data optimization for supply chain & waste management using AI	Unilever X SAP (UK / Netherlands)
3. Knowledge & Capacity Building	Farmer training in sustainable practices	Soil health, biodiversity, regenerative techniques	Barilla Sustainable Farming program (Italy); Nestlé Nescafé Plan 2030 (27 countries)
	Water stewardship & irrigation co-investment	Improve water efficiency for crops	Heineken (Spain — Doñana)
4. Green Technology & Innovation	Product innovation	Develop sustainable alternatives to conventional products	La Belle-Iloise plant-based seafood (France); Unilever sustainable brands (UK / Netherlands)
	Packaging innovation	Reduce waste & environmental impact	Apeel Sciences edible coatings (USA); Lipton biodegradable tea bags (UK, Netherlands)
	Sourcing & agricultural innovation	Reduce emissions via regenerative or precision practices	Lipton: pesticide-free estates, drone-assisted fertilization, IoTEA™ platform (Kenya, Rwanda, Tanzania)
	Process & logistics efficiency	Reduce waste, energy use, and emissions in storage & transport	Carrier Transicold Vector eCool (Europe)
5. Waste Management & Resource Efficiency	Retail-level waste reduction	Market imperfect produce, AI pricing for perishables	Tesco "Perfectly Imperfect" (UK); Carrefour dynamic pricing (Spain)
	By-product valorization	Convert waste streams into new products	AB InBev "EverGrain" (spent barley flour) (Belgium/USA)
	Logistics optimization	Route planning and digital tools to reduce mileage, fuel consumption, and emissions in delivery operations	Dassault Systèmes route planning for a major grocery retailer (528 km and 7.6 tCO_2e avoided per day)
6. Governance & Collaboration Models	Long-term sourcing contracts	Stabilize prices and encourage sustainable practices	Mars multi-year cocoa agreements (USA)
	Farmer support centers & co-investment	Agronomy training, improved seeds, co-financed infrastructure	FrieslandCampina Foqus planet (Netherlands)
	Pre-competitive coalitions for regenerative agriculture	Shared metrics, pooled R&D feedback, cross-sector governance	World Living Soils Forum Advisory Board — Pernod Ricard, Moët Hennessy/LVMH, Nestlé (France)

Exhibit 6 – Source: Ardabelle Capital interviews and analysis.

Luxury and Fashion

Overview of risks and materiality

The luxury sector – spanning ready to wear, leather goods, watches, jewelry, shoes and accessories – is structurally exposed to asymmetric shocks that test resilience. Once relatively shielded from structural pressure, it is now facing a triple imperative: sustainability, traceability, and geopolitical resilience. According to a 2025 McKinsey report on the state of fashion[178], more than 70% of emissions in the sector stem from upstream value chain stages (raw materials, subcontracting, logistics), exposing brands to mounting pressure to reduce Scope 3 emissions. Consumer expectations are shifting too: nearly 60% of younger buyers now list sustainability as a key purchase criterion, but they are not willing to compromise on aesthetics or exclusivity.

Against this backdrop, major players (LVMH, Kering, Hermès, and Prada, among others) are rethinking the structure of their supply chains. This includes reinvesting in shorter, localized, circular supply loops and securing inputs amid rising scarcity of premium materials (organic cotton, cashmere, silk, and plant-based leather, etc.). Luxury as a symbol of rarity and control remains dependent on long, opaque, and often polluting global chains. The transition toward a truly desirable and sustainable industry will require deep investments in traceability (blockchain, product passports, AI-driven audits), material innovation, and partial relocalization – notably in Southern Europe and North Africa.

As a result, resilience becomes inseparable from brand integrity. Reshoring critical capabilities, securing raw materials with verified ethical and environmental standards (e.g. traceable cashmere, certified merino wool, animal welfare protocols), and building shorter, trusted supplier relationships are both reputational safeguards and strategic levers to maintain pricing power, consumer loyalty, and regulatory compliance in an increasingly volatile global environment.

Because value is concentrated in provenance, craftsmanship, and exclusivity, small disturbances can cascade into outsized impacts on revenue and brand equity. Four vectors dominate:

- Demand shocks arise from macro slowdowns, travel restrictions, or volatility in “very important clients” (VICs), whose disproportionate share of spending on luxury magnifies swings in sentiment. Resilience requires both absorptive buffers such as liquidity and balanced client portfolios, as well as adaptive diversification of growth beyond VIC dependence.[179] However, VIC can also represent a source of resilience, as their spending power is less affected by economic cycles. In this context, overexposure to China, both as a manufacturing base and as a critical end-market, creates strategic dependence vulnerable to geopolitical tensions.
- Supply shocks stem from artisanal bottlenecks and scarce raw inputs (hides, metals, gemstones), where climate events, trade frictions, or mining constraints can create multi-year long waiting lists. Building resilience entails investing in supplier enablement

[178] https://www.businessoffashion.com/articles/sustainability/the-state-of-fashion-2025-report-sustainability-decarbonisation-circular-emission/
[179] McKinsey’s *“The State of Luxury: How to navigate a slowdown”*

and digital traceability to stabilize quality and timing under stress, aligning with supply-chain resilience practices highlighted by the World Economic Forum.[180]

- Reputation shocks propagate fastest, from counterfeiting, hidden subcontracting, ethical breaches, lack of diversity, image scandals or traceability failures, directly undermining the authenticity that justifies price premiums. For example, early 2026, Dolce & Gabbana was accused of racism due to a 100% white casting for their latest fashion show. Here resilience is primarily adaptive: hard-wiring digital authentication, real-time monitoring, and transparency to contain reputational contagion.[181]
- Regulatory shocks emerge as due diligence, biodiversity, and climate rules reshape sourcing and raise compliance costs. Transformative resilience is needed: rethinking product design, material substitution, and circularity to remain viable under tightening constraints.[182]

Recent data illustrate how these shocks translate into potential structural fragility. Bain in 2024[183] valued the global luxury market at €1.48 trillion, essentially flat year-on-year, with contractions in key segments such as luxury cars (−5%) and watches/shoes (−5–7%). The customer base shrank by about 50 million since 2022, while spending became more concentrated: the top 2% of clients now drive about 45% of purchases, up from 35% in 2021. McKinsey notes that over 80% of growth since 2019 came from price increases, a lever now reaching its limit as consumers push back. Combined with Chinese demand normalization and persistent macroeconomic uncertainty, these trends grow and regulatory pressures harden**.** In such an environment, resilience cannot remain reactive or defensive; it must be embedded as a forward-looking strategy to absorb volatility, adapt business models, and transform sourcing and client engagement before shocks cascade into systemic risks.

Product authenticity, counterfeiting craftmanship risks

The artisanal supply-chain model that underpins luxury creates fragility. The extreme fragmentation of subcontracting, widespread reliance on informal workshops, and lack of transparency beyond Tier 1 make luxury brands acutely vulnerable to social, legal, and reputational risks. Small workshops in Europe and beyond face limited compliance capacity, making illicit subcontracting endemic. LeBaron et al. (2021)[184] emphasize that fragmented subcontracting chains are structurally vulnerable to labor-rights violations, with audits rarely sufficient to capture hidden tiers. Illicit subcontracting erodes provenance claims and allows violations (labor, safety, environmental) to proliferate in hidden tiers. The 2025 Loro Piana case – in which a Chinese subcontractor was exposed for underpaid and unsafe working conditions – exemplifies how hidden tiers can trigger major brand crises. In July 2025, Loro Piana[185]–a luxury cashmere brand under LVMH–was placed under judicial administration by an Italian court due to labor exploitation within its supply chain. The ruling found that production had been subcontracted via front firms to Chinese-owned workshops operating illegally: workers were paid as little as €4 per hour, worked up to 90 hours per week, including undocumented labor and unsafe conditions. Because customer trust and brand value in luxury rest on

[180] World Economic Forum. (2024). *Global risks report 2024*.
[181] See Organisation for Economic Co-operation and Development. (2023). *OECD guidelines for responsible business conduct*.
[182] See United Nations Environment Program. (2022). *Sustainability and fashion: Next steps for a circular economy*
[183] Bain & Company, & Altagamma. (2024). *Luxury in transition: Securing future growth* (Luxury Goods Worldwide Market Study, Spring 2024).
[184][184] Genevieve LeBaron's article, *The Role of Supply Chains in the Global Business of Forced Labour* (2021, *Journal of Supply Chain Management*)
[185] Reuters. (2025, July 14). *LVMH's Loro Piana put under court administration in Italy over labour exploitation*.

provenance, authenticity and craftsmanship, the combination of these counterfeiting and subcontracting risks represents a serious reputational shock. Even ignoring direct revenue loss, erosion of consumer confidence–or exposure of a major scandal–can reduce pricing power (both at first sale and resale), damage brand equity, and heighten regulatory scrutiny.

Another consequence of this model regards counterfeiting which is estimated to siphon off tens of billions annually from luxury revenues, while illicit subcontracting erodes provenance claims. A Bain study [186] underscores that "provable origin and authenticity are the backbone of luxury value capture." OECD[187] estimates put counterfeits at roughly 2.5% of global trade, or about $450–$460 billion, with luxury categories disproportionately targeted, translating into tens of billions in annual revenue erosion and brand dilution for top houses. McKinsey[188] warns that luxury supply chains are "under pressure" to deliver both craftsmanship and scale, and that opacity increases exposure to fraud, counterfeiting, and reputational crises. Reputational harm goes beyond lost sales.

Scope 3 emissions, raw materials, biodiversity and animal welfare

Structure of total emissions for 4 major actors of the luxury industry

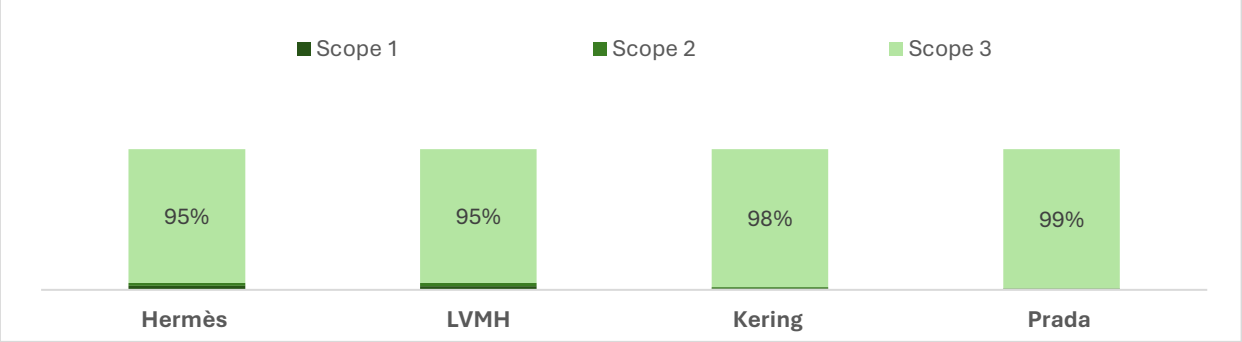

Exhibit 7 – Source: Ardabelle Capital analysis, based on the 2024 Sustainability or Integrated Reports of all 4 companies

For Luxury and Fashion brands, the overwhelming share of greenhouse gas (GHG) emissions lies in Scope 3 value-chain activities (typically more than 70%), particularly in upstream categories such as raw material production and Tier-2 processing.[189]

Among Scope 3 emissions and more specifically among raw materials, animal-derived inputs like leather, wool and cashmere are the most emission-intensive due to methane from ruminant livestock and land-use change from pasture/feed expansion, making them a concentrated hotspot for climate and biodiversity risk.[190] Commodity-driven deforestation adds to this footprint, with an estimated 27% of global forest loss linked to agriculture commodities like beef and fiber crops.[191] Beyond farming**,** energy-intensive mining and refining of gold and gemstones create significant Scope-3 emissions, particularly in regions with fossil-heavy grids. Finally, Tier-2 manufacturing processes such as tanning, dyeing and finishing are

[186] Bain & Company, & Altagamma. (2024). *Luxury in transition: Securing future growth* (Luxury Goods Worldwide Market Study, Spring 2024)
[187] OECD/EUIPO. (2016). Trade in counterfeit and pirated goods: Mapping the economic impact. OECD Publishing
[188] McKinsey & Company, & The Business of Fashion. (2023). *The state of fashion: Luxury 2023*.
[189] McKinsey & Company. (2020). *Fashion on climate: How the fashion industry can urgently act to reduce its greenhouse gas emissions*.
[190] The Wall Street Journal. (2021, December 29). *Fashion's climate problem: Methane from cows*.
[191] Curtis, P. G., Slay, C. M., Harris, N. L., Tyukavina, A., & Hansen, M. C. (2018). Classifying drivers of global forest loss. *Science, 361*(6407), 1108–1111

major energy and chemical hotspots, sometimes representing up to 45–70% of Scope-3 impacts. While downstream use and care matter less for apparel than for luxury autos or electronics, product longevity and resale can still materially reduce lifecycle impacts.[192]

Commodity-driven deforestation is one of the largest sustainability challenges tied to raw materials in Luxury and Fashion. Permanent forest conversion for agriculture commodities is responsible for roughly 27% of global forest loss.[193] Between 2001 and 2015, just seven commodities – cattle, oil palm, soy, cocoa, rubber, coffee and plantation wood fiber – replaced nearly 71.9 million hectares[194] of forest, more than twice the size of Germany. Within this, cattle pasture stands out as the single largest driver, having replaced almost 45.1 million hectares over the same period.

These structural vulnerabilities–ranging from artisanal bottlenecks and remote subcontracting to high upstream emissions and biodiversity pressures–illustrate that luxury's exposure is not only financial but also reputational, regulatory, and environmental. The combination of provenance risks, counterfeiting, labor violations, and carbon-intensive supply chains underscores that reactive measures alone are insufficient; resilience must be operationalized across the value chain. The reliance on animal-derived materials compounds both ethical and ecological risks. Luxury and Fashion brands often use leather, wool, down and feathers, yet industry oversight is strikingly low: fewer than 3% of global wool supplies are certified for animal welfare, about 4% for down and feathers, and less than 1% for alpaca wool.[195] This leaves supply chains exposed to persistent welfare concerns such as live-plucking, mulesing, intensive confinement, poor transport and inhumane slaughter practices. Beyond the welfare dimension, the biodiversity cost is significant.

Operational levers and industry practices

Financing sustainable transitions

Luxury's sustainability transition is constrained by the capital gap facing its small and medium-sized suppliers. Independent tanneries, watch component workshops, and artisanal jewelers often operate with narrow margins, leaving them unable to fund low-carbon upgrades, clean tanning facilities, or traceability infrastructure, in the medium term. This financing asymmetry exposes brands to regulatory and reputational risk since most Scope 3 emissions lie downstream. To address this, several luxury houses have begun experimenting with blended finance and co-investment models that mirror those seen in other industries. Chanel's Nevold initiative, launched in 2025, channels an estimated €50–80 million into building a shared European recycling and regeneration network for textiles, leather, and fabric offcuts. The project functions as a semi-open B2B platform, giving smaller ateliers access to high-quality recycled materials that meet luxury standards without requiring prohibitive investment.[196] Similarly, ID Genève, a Swiss circular watch brand, has attracted impact investors to scale its repairable and modular "Circular S" line, using recycled steel and reclaimed movements to

[192] Bain & Company. (n.d.). *Luxury and sustainability: The new value drivers*.
[193] Curtis, P. G., Slay, C. M., Harris, N. L., Tyukavina, A., & Hansen, M. C. (2018). Classifying drivers of global forest loss. *Science*
[194] World Economic Forum. (2021, February 15). *7 commodities that are driving the world's forests to destruction*.
[195] Four Paws International. (2023, October 17). *Animal use in fashion and little oversight of welfare*.
[196] Paris Select. (2025, March 14). *Chanel launches Nevold: A €50–80 million circular materials platform for luxury recycling*. Paris Select Magazine.

prove that circular luxury manufacturing can be economically viable.[197] These financing mechanisms show how shared infrastructure and targeted capital deployment can help SMEs participate in decarbonization rather than be excluded by it.

Data, measurement, and compliance

Transparency and traceability have become central to compliance in luxury supply chains. The sector faces escalating pressure from the EU's Ecodesign for Sustainable Products Regulation (ESPR), which will mandate digital traceability for textiles, jewelry, and leather goods entering the European market. In response, leading groups are investing in common digital infrastructures. The Aura Blockchain Consortium, founded by LVMH, Prada, and Cartier, already records more than 50 million products on a shared ledger, giving consumers digital proof of authenticity while providing brands with a common compliance platform.[198] Tiffany & Co. is another example: in its 2024 Sustainability Report, it claimed 99.99% traceability for newly sourced, individually registered diamonds to mine or approved supplier origin; and 100% traceability of colored gemstones to country of origin. It also leads in applying supplier codes of conduct through the Responsible Jeweler Council standards for its suppliers of diamonds and metals.[199] Gucci has also reported on measurable reductions in water, chemicals, and material waste via its *Scrap-less* initiative, which tracks quantities of off-cut leather, water saved, energy saved etc., thus closing the data loop on production inefficiencies and environmental impact.[200] These digital infrastructures lower verification costs for SMEs and anticipate upcoming regulation, while also building consumer trust in certified origin and reduced-impact materials.

Knowledge and capacity building

Financial support and traceability systems are insufficient unless suppliers also have the technical and human capacity to implement sustainable practices. Many luxury SMEs lack expertise in emissions accounting, water management, or material substitutions. Capacity-building therefore becomes an essential lever of transformation. Balenciaga's partnership with the Italian biotech company Sqim to create Ephea™, a mycelium-based leather alternative, involved cross-functional collaboration between scientists, designers, and manufacturing technicians – an implicit model of embedded capacity-building within product innovation.[201] By engaging SMEs, research institutions, and start-ups, luxury houses are effectively transferring know-how and creating a shared technical language for sustainability across their supplier networks. Gucci's material innovation labs have worked with their supply base to incorporate bio-based alternatives such as Demetra, training teams in how to use new plant-based or partially bio-based leather substitutes without compromising craftsmanship and quality.[202] Hermès' eco-design research is another example: in its "Eco-design" program, Hermès has tested silk and cashmere yarns made from recycled waste and is exploring acoustic insulation panels from textile waste, combining design expertise, material R&D, and artisan knowledge in

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[197] WatchTime India. (2024, June 5). *ID Genève secures impact investment to scale its Circular S line of modular, repairable luxury watches*.

[198] Vogue Business. (2024, February 19). *Aura Blockchain Consortium surpasses 50 million luxury items registered on shared ledger*.

[199] Tiffany & Co. (2024). *Sustainability report 2024*.

[200] Gucci. (2024). *Gucci Scrap-less: Reducing waste and improving resource efficiency across leather supply chains*.

[201] Vogue Business. (2022, October 12). *Balenciaga debuts Ephea™, a mycelium-based leather alternative developed with Italian biotech Sqim*

[202] Gucci. (2023, July 18). *Gucci launches Demetra: A new-generation, bio-based material blending sustainability and craftsmanship*. Gucci Equilibrium.

eco-design approaches.[203] These capacity-building efforts ensure that SMEs aren't just recipients of policies but active innovators.

Green technology and innovation

Innovation represents the most visible and compelling lever of sustainability in the luxury sector. Leather, precious metals, and gemstones–the industry's most iconic materials–are also its largest environmental hotspots. Material substitution and novel inputs are central to reducing upstream emissions. Bananatex**,** a biodegradable fabric made from Abacá banana plant fibers, offers a sustainable alternative to traditional textiles. Developed by Swiss brand QWSTION, Bananatex is used in luxury accessories and bags, providing a durable and eco-friendly option that reduces environmental impact,[204] Similarly, Hermès' eco-design research has extended to the construction of its L'Isle-d'Espagnac workshop, which uses sustainable materials such as local Charente stone and straw insulation, integrates solar panels, and maximizes natural light–an example of how eco-design and technological innovation can merge at the infrastructure level.[205] In parallel**,** Stella McCartney has emerged as the luxury sector's pioneering force in sustainable material innovation, demonstrating that radical environmental commitment can coexist with commercial success. Since 2001, the brand has refused to use leather, fur, or skins–a stance once considered commercially risky that drove early investment in next-generation materials. Her collaboration with Bolt Threads to develop Mylo mycelium leather–a bio-fabricated material grown from mushroom roots–resulted in the first luxury mycelium bag (Frayme Mylo, 2021), validating both technical viability and consumer acceptance at premium price points.[206] The brand has also pioneered ECONYL regenerated nylon (from recycled fishing nets), regenerated cashmere from textile waste, and bio-based acetate for accessories–each substituting virgin, resource-intensive materials with circular alternatives.[207] This innovation strategy has become a core driver of brand differentiation, attracting sustainability-conscious luxury consumers and maintaining strong commercial performance with revenues exceeding €50 million annually.[208] By proving that cruelty-free, low-carbon luxury is both feasible and profitable, Stella McCartney has shifted industry norms and encouraged broader adoption of sustainable materials. Together, these examples show that green innovation in luxury is evolving beyond boutique experimentation into a scalable industrial transformation, turning material science and eco-design into core strategic capabilities.

Waste management and resource efficiency

Waste minimization has become a defining operational challenge in the luxury sector, given the reputational risks of overproduction and the destruction of unsold inventory. Unlike fast fashion, luxury brands have the craftsmanship culture to embed circularity at scale. Zerolab, a Florence-based SME, collaborates with local leather accessory manufacturers to collect unused leather strips and off-cuts. These materials are repurposed into new products, significantly reducing the estimated 180 tons of leather waste disposed of annually in Tuscany.

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[203] Hermès. (2024). *Eco-design at Hermès: Integrating sustainability into materials and creation processes*. Hermès International.
[204] QWSTION. (2024). *Bananatex®: The world's first durable, biodegradable fabric made from Abacá banana fibers*.
[205] Hermès. (2025). *Hermès inaugure sa vingt-quatrième maroquinerie à L'Isle-d'Espagnac (Charente)*
[206] Stella McCartney. (2021). *Introducing the Frayme Mylo bag: the world's first luxury mycelium leather handbag*
[207] Stella McCartney. (2023). *Sustainability report: Material innovation and circular design*
[208] Business of fashion. (2023). *Stella McCartney proves sustainable luxury can be profitable*

Zerolab also engages the local community through workshops on sustainable design, demonstrating that circular practices can be embedded in both production and education.[209] Similarly, MUD Jeans, a B-Corp certified brand from the Netherlands, operates a circular denim model that incorporates up to 40% post-consumer recycled content. Customers can lease jeans for a monthly fee and return them for recycling or upcycling after one year. This model promotes the reuse of materials, reduces textile waste, and transforms resource efficiency into a brand value rather than a cost center.[210] Together, these examples show how SMEs in the luxury and premium sector are pioneering circular business models that turn waste into feedstock and extend product life cycles, aligning environmental responsibility with craftsmanship and innovation.

Governance and collaboration models

True resilience in luxury supply chains depends on governance models that go beyond transactional compliance. The most effective brands are forming coalitions and long-term partnerships that distribute responsibility and share innovation costs. The Aura Blockchain Consortium represents one such governance innovation, allowing competitors to pool resources around traceability rather than duplicating systems.[211] Louis Vuitton's Oratoire Atelier, a bioclimatic workshop in central France, exemplifies a collaborative approach to sustainable infrastructure. Designed with eco-friendly materials like recycled metal and Forest Stewardship Council-certified wood, and featuring solar panels and natural ventilation, the Oratoire integrates sustainability into its construction and operations, setting a precedent for future facilities.[212] Other actors, such as L'Oréal, foster innovation through programs like "L'AcceleratOR",[213] which aims to accelerate the emergence and large-scale deployment of sustainable solutions capable of addressing the major challenges facing climate, nature and circularity. At the SME level, Veja, a French footwear brand, partners with recycling cooperatives in Brazil to convert PET plastic bottles into shoe linings. This initiative not only reduces waste but also supports local communities by providing fair compensation to waste pickers, demonstrating how circular practices can be embedded in global supply chains.[214] These initiatives mirror the cooperative insurance and shared-finance models emerging in other sectors: they transform compliance from an individual cost into a collective investment. By embedding collaboration and co-investment at the center of their operational strategies, luxury brands are beginning to translate sustainability compliance into a durable source of competitive and supply-chain resilience.

[209] Zerolab. (2025, March 15). *Luxury brands and the circular economy: A Florentine example*.
[210] MUD Jeans. (2025). *MUD Jeans: Circular denim for a sustainable future*.
[211] Aura Blockchain Consortium. (2024). *Aura Blockchain Consortium: Luxury traceability and transparency*.
[212] Louis Vuitton. (2023). *Louis Vuitton Oratoire Atelier: Sustainable and bioclimatic design*
[213] L'Oréal. (2025). L'Oréal devoile 13 premiers acteurs du changement intégrant son programme d'innovation durable « l'AcceleratOR », doté de 100 millions d'euros
[214] Veja. (2024). *Sustainable footwear: PET bottles to sneakers*.

Operational levers and industry practices in the Luxury and Fashion sector

Category	Operational Lever / Practice	Description	Example(s)
1. Financing Sustainable Transitions	Shared investment in SME upgrades	Luxury houses provide blended finance, co-investment, or impact investment mechanisms to enable SMEs to adopt low-carbon technologies, circular production methods, and traceability infrastructure. Helps mitigate regulatory and reputational risks while supporting upstream Scope 3 emissions reduction.	Chanel's Nevold (recycled textile/leather B2B platform); ID Genève "Circular S" modular watches (recycled steel and reclaimed movements)
	Micro-grants & low-interest loans	Small-scale financial support to artisanal suppliers to adopt energy-efficient processes or new sustainable materials	Hermès supplier energy-efficiency support programs; Kering micro-grants for leather workshops
2. Data, Measurement, and Compliance	Traceability and product registration	Digital platforms or blockchains record product origin, material sourcing, and sustainability metrics, enabling brands to meet regulatory requirements and provide consumers with certified transparency	Aura Blockchain Consortium (traceable luxury products); Tiffany & Co. (diamond and gemstone origin tracking)
	Environmental monitoring & reporting	Track energy, water, chemical usage, and material waste throughout production; supports ESG reporting and continuous improvement	Gucci Scrap-less Initiative (tracks leather off-cuts, water, energy, and material savings)
	Supplier codes & auditing	Implement supplier standards and codes of conduct, coupled with audits to ensure environmental and social compliance	Responsible Jeweler Council (Tiffany & Co.)
3. Knowledge and Capacity Building	Supplier training	Upskilling artisans and SMEs in sustainable materials, circular design, and eco-production techniques	Gucci Material Innovation Labs (training for bio-based leather substitutes)
	Cross-functional innovation partnerships	Collaborations between brands, SMEs, and research labs for developing new materials and sustainable technologies	Balenciaga x Sqim Ephea™ (mycelium leather); Bolt Threads & Stella McCartney Mylo™
	Eco-design programs	Integrate sustainability principles in product and infrastructure design; share knowledge with artisans	Hermès Eco-design Program (recycled silk and cashmere yarns, textile waste insulation panels)
4. Green Technology and Innovation	Material substitution	Replace high-impact materials (leather, virgin plastics) with bio-based, recycled, or bio fabricated alternatives	QWSTION Bananatex® (banana-fiber textiles); Stella McCartney Mylo™
	Sustainable infrastructure	Construct workshops or facilities using low-impact materials, energy efficiency measures, and renewable energy	Hermès L'Isle-d'Espagnac Workshop (sustainable materials, solar panels, natural lighting)
	Circular product design	Design products for longevity, modularity, or recyclability to reduce environmental footprint	MUD Jeans (circular denim leasing and recycling)

5. Waste Management and Resource Efficiency	Upcycling and scrap utilization	Convert production scraps and unsold inventory into new products, minimizing waste and material losses	Zerolab (repurposed leather off cuts); Veja (PET plastic bottles into shoe linings)
	Circular supply chains	Leasing, take-back, or repair programs extend product life cycles and reintroduce materials into production	MUD Jeans circular leasing model
	Community engagement	Include local communities in recycling initiatives to promote social and environmental impact	Zerolab workshops; Veja cooperatives in Brazil
6. Governance and Collaboration Models	Multi-brand consortiums	Competitors collaborate to share infrastructure, data platforms, or R&D, reducing redundancy and scaling sustainability efforts	Aura Blockchain Consortium (traceability platform)
	Collaborative infrastructure	Sustainable production facilities or labs co-funded or co-managed by multiple stakeholders	Louis Vuitton Oratoire Atelier (bioclimatic, sustainable workshop)
	SME partnerships	Work directly with SMEs to integrate circularity and sustainability into global supply chains	Veja (recycling cooperatives in Brazil)
	Pre-competitive innovation platforms	Open-access initiatives where competitors share R&D and sustainable material innovations	Kering Sustainability Innovation Lab

Exhibit 8 – Source: Ardabelle Capital interviews and analysis.

For luxury, resilience is inseparable from provenance and people. The sector's premium depends on traceable materials, compliant artisanal labor, and long-lived products. The strategic lesson is clear: sustainability is not philanthropy but the operating system of brand value. Without empowered SMEs, transparent supply chains, and circular business models, luxury brands risk eroding their most asset – trust.

SMEs as leverage points in value-chain resilience

A recurring insight emerging from the sector analyses is that value-chain resilience and decarbonization are often not determined by large firms alone, but by a limited number of structurally central SMEs whose operational choices condition the performance of the entire ecosystem. In many industries, SMEs occupy critical junctions of the value chain–such as formulation, processing, packaging, logistics, specialty components, or intermediate services–where disruptions, inefficiencies, or strategic misalignment can propagate rapidly both upstream and downstream. From a complex systems perspective, these firms operate as localized points of amplification, where relatively small operational changes can generate disproportionately large systemic effects.

This dynamic can be interpreted through the lens of non-equilibrium systems theory developed by Ilya Prigogine[215]. In Prigoginian systems operating far from equilibrium, local fluctuations may be amplified rather than absorbed, leading to irreversible structural change when the system approaches a bifurcation point. Global supply chains facing climate, regulatory, and geopolitical pressures increasingly exhibit such characteristics. In this context, strategically positioned SMEs can be understood as "islands of contagion": once they adopt more resilient

[215] Prigogine, I. (1980). *From being to becoming: Time and complexity in the physical sciences*. W. H. Freeman.

or low-carbon practices, these practices diffuse through contractual dependencies, technical standards, and coordination mechanisms across the value chain.

Targeted resilience and decarbonization efforts focused on these SMEs can therefore generate disproportionate systemic effects. Rather than attempting to transform entire supply networks simultaneously, effective strategies increasingly consist of identifying and supporting a limited number of keystone suppliers whose operational upgrading enables cascading improvements across multiple tiers. This approach is particularly relevant in fragmented sectors such as Food and Beverage, beauty, construction, and fashion, where SMEs account for a significant share of value added but often lack the financial or technical capacity to independently absorb the costs of transition.

When SMEs located at nodal points of the value chain upgrade their production processes, energy efficiency, traceability systems, or carbon accounting practices, the benefits extend well beyond the firm itself. Downstream firms benefit from improved reliability, regulatory compliance, and Scope 3 emissions performance, while upstream partners face clearer expectations and stronger coordination signals. In this sense, SMEs act as transmission mechanisms for resilience and decarbonization, translating strategic objectives defined by lead firms or public policy into operational change throughout the supply chain.

This perspective has important implications for resilience and transition strategies. Systemic transformation does not require the simultaneous transformation of all actors, but rather the identification of intervention points with the highest multiplier effects. Supporting strategically positioned SMEs through preferential financing, technical assistance, long-term contractual visibility, or shared data infrastructures can unlock rapid gains in robustness, sustainability, and adaptability at the ecosystem level.

From both a policy and corporate perspective, this reinforces the case for differentiated support mechanisms that recognize the strategic role of certain SMEs beyond their individual size. It also explains why supplier engagement strategies focused on a limited number of critical SMEs often outperform broad but shallow approaches. Ultimately, resilience and decarbonization at scale are built not only through the actions of lead firms, but through the capacity of key SMEs to act as accelerators of collective transition within complex production systems.

4. Four scenarios for Europe's economy in an era of climate shocks and geopolitical volatility

How will the macro- and micro-level levers to build resilience and sustainability that we discussed in the previous chapter influence economic growth at the European scale? Beyond their environmental and social benefits, these measures may also reshape productivity patterns, investment flows, and competitiveness within the European economy. Inevitably, they will require trade-offs and strategic choices. Understanding their potential economic impact is therefore crucial to ensure that the transition toward more sustainable and resilient systems supports long-term growth and prosperity.

In this chapter, we outline four economic scenarios we have modeled to 2050, ranging from a continuation of the status quo, at one end, to a full-scale adoption of resilient green measures at the other. The scenarios are based on two axes**:** first, the level of investment in resilience (low vs. high) and, second, the commitment to sustainability (low vs. high). For each of the scenarios, we measure both the potential GDP gains or losses and the gap between those outcomes and a baseline potential for GDP by 2050 excluding climate and other shocks. The range of outcomes is very substantial: the resilient green option is the best-case scenario and would be a net positive to economic growth in Europe, contributing an annual average GDP growth of 1.6% and exceeding GDP potential in 2050 by 14%. In the worst-case scenario, that of the status quo, GDP would barely grow at 0.4% annually with the gap between GDP and potential GDP growing to -16%.

What Europe will look like in 2050 if nothing changes

Projected climate impacts under ΔT = 2.4°C by 2050

Boreal region (Northern Europe)

Northern Europe could initially appear to gain from warming, as longer growing seasons and milder winters increase yields for barley, oats, and forest biomass. In Finland, the agricultural season has already extended by nearly one month compared to the 1970s[216]. However, these advantages are counterbalanced by soil saturation, fungal outbreaks, and storm damage. The 2018 Scandinavian windstorms caused billions in forestry losses, revealing the fragility of these "winners." Melting permafrost in northern Scandinavia destabilizes infrastructure, while the northward spread of bark beetles, once constrained by winter cold, now devastates spruce

[216] Organization for Economic Co-operation and Development. (2023). *Policies for the future of farming and food in the European Union*. OECD Publishing

forests.[217] Thus, while productivity may rise modestly, the region faces mounting costs from forest management, erosion, and flooding.[218]

Atlantic region

Along the Atlantic façade–from western France to Ireland and northern Spain–warmer air masses intensify precipitation and storm activity. The IPCC in its Sixth Assessment Report projects up to 20% more winter rainfall, leading to more frequent flood events like those of 2021 in Germany and Belgium, which caused over €30 billion in damage[219]. Coastal areas face repeated storm surges and infrastructure stress; ports, transport corridors, and energy grids require massive adaptation investment. Agriculture experiences waterlogging and shorter field work windows. In Brittany and Galicia, livestock farming already faces challenges from wet soils and fodder scarcity, forcing farmers to invest in drainage and feed imports.[220] The combination of recurring floods and high insurance costs makes the region emblematic of Europe's rising adaptation burden.

Continental region (Central & Eastern Europe)

Central and Eastern Europe increasingly oscillate between summer droughts and flash floods. The 2015 and 2022 heatwaves reduced maize yields in Hungary and Romania by nearly 30%, while rivers like the Danube alternated between record lows–blocking transport–and destructive floods.[221] Water management systems designed for historical patterns now face dual stress. Heatwaves intensify urban heat-island effects in cities such as Budapest and Warsaw, threatening public health and productivity. Rural economies, heavily dependent on grain exports, grow more volatile, smaller farms without irrigation systems risk insolvency. Social vulnerability rises as income disparities widen between well-adapted and marginal regions.[222]

Mountain regions (Alps, Pyrenees, Carpathians)

The mountain ecosystems of Europe warm faster than the continental average. The European Alps have already lost 60% of their glacier volume since 1850, and under 2.7°C warming, many low-altitude glaciers could vanish entirely by 2050.[223] The disappearance of permafrost increases landslide and rockfall risks, threatening villages and transport routes like the Mont-Blanc corridor.[224] Biodiversity shifts upward, but many alpine species–such as the snow vole and edelweiss–run out of habitat. Economically, winter tourism collapses as snow reliability declines below 1,500 m; in the French Alps, ski resorts already rely on costly artificial snow

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[217] Schaller, N., Sillmann, J., & Cramer, W. (2021). *Future climate risk in Europe: An integrated assessment. Nature Climate Change, 11*(9), 783–792

[218,] European Environment Agency. (2023). *Climate risks to the economy in Europe.* European Environment Agency

[219] Schaller, N., Sillmann, J., & Cramer, W. (2021). *Future climate risk in Europe: An integrated assessment. Nature Climate Change, 11*(9), 783–792

[220] European Environment Agency. (2023). *Climate risks to the economy in Europe.* European Environment Agency

[221] Joint Research Centre. (2021). Global warming could more than double the costs caused by drought in Europe, study finds. European Commission.

[222] European Investment Bank. (2025). *European agriculture faces growing climate risks that EU can help counter, new study finds.* EIB Press Release.

[223] Zekollari, H., Huss, M., & Farinotti, D. (2020). *Modelling the future evolution of glaciers in the European Alps under climate change. The Cryosphere*

[224] Schaller, N., Sillmann, J., & Cramer, W. (2021). *Future climate risk in Europe: An integrated assessment. Nature Climate Change, 11*(9), 783–792

production that consumes scarce water.[225] Meanwhile, hydropower reservoirs fluctuate, disrupting energy reliability for entire regions.

Mediterranean region

Persistent heatwaves exceeding 45°C, such as those recorded in Greece and southern Spain in 2023, could become the norm rather than exceptions. The IPCC[226] (2022) identifies the Mediterranean as a "hotspot" where precipitation may fall by 20–30%, drastically reducing soil moisture. This leads to water shortages affecting both agriculture and urban centers. In 2022, the Po River drought in Italy reduced hydropower generation and maize yields by nearly 30%, an indication of what may become chronic[227]. Olive groves and vineyards–symbols of Mediterranean identity–are already retreating northward as pests like the olive fruit fly and Xylella[228] fastidiosa thrive in warmer climates. Tourism, once the region's economic backbone, also suffers: beach erosion, heat stress, and forest fires–such as those in Greece, Portugal, and Sardinia–discourage summer travel. As rural livelihoods collapse, land abandonment accelerates, reshaping entire landscapes and weakening social cohesion.[229]

Coastal zones

Sea-level rise of 25 - 35 cm by 2050 under current trends threatens Europe's densely populated coastlines.[230] The Netherlands, Venice, and coastal Poland already invest billions in sea walls and flood barriers, yet saltwater intrusion jeopardizes freshwater aquifers and agriculture. Estuarine ecosystems such as the Camargue or Doñana wetlands shrink, undermining their role as natural flood buffers. Coastal tourism–critical in southern France and Croatia–faces erosion and infrastructure loss. Some communities begin to consider managed retreat, as maintaining defenses becomes economically untenable. The symbolic loss of heritage sites–Venice's lagoon, the Amalfi coast–illustrates how cultural and environmental degradation intertwine.

Concluding perspective: the "No Green, No Resilient" Europe

In a "No Green, No Resilient" scenario, Europe's 2.4°C trajectory turns climate stress into a structural shock multiplier. Lacking green transition and adaptive infrastructure, the continent's resilience systems–economic, institutional, and ecological–erode simultaneously. Droughts in the south disrupt food and energy security, floods in the west and center damage logistics and housing, and forest degradation in the north weakens carbon sinks. Without investment in resilient grids, diversified agriculture, and natural buffers, each crisis compounds the next. Economic and financial resilience falter as reconstruction costs rise, insurance markets contract, and public debt mounts. Social resilience weakens under uneven protection: southern and rural populations face chronic hardship, spurring migration toward better-adapted regions. Institutional trust declines as repeated shocks expose governance gaps and

[225] European Environment Agency. (2023). *Climate risks to the economy in Europe.* European Environment Agency
[226] Intergovernmental Panel on Climate Change. (2022). *Climate Change 2022: Impacts, adaptation, and vulnerability* (Contribution of Working Group II to the Sixth Assessment Report). Cambridge University Press
[227] Joint Research Centre. (2021). Global warming could more than double the costs caused by drought in Europe, study finds. European Commission.
[228] Organization for Economic Co-operation and Development. (2023). Policies for the future of farming and food in the European Union. OECD Publishing
[229] European Investment Bank. (2025). *European agriculture faces growing climate risks that EU can help counter, new study finds*. EIB Press Release.
[230] Intergovernmental Panel on Climate Change. (2022). *Climate Change 2022: Impacts, adaptation, and vulnerability* (Contribution of Working Group II to the Sixth Assessment Report). Cambridge University Press

unequal recovery capacity. Ecosystem resilience collapses in parallel, as degraded soils, deforested slopes, and shrinking wetlands lose their ability to absorb floods or heatwaves.

Main climate change impacts on the agricultural sector for the main biogeographical regions in Europe

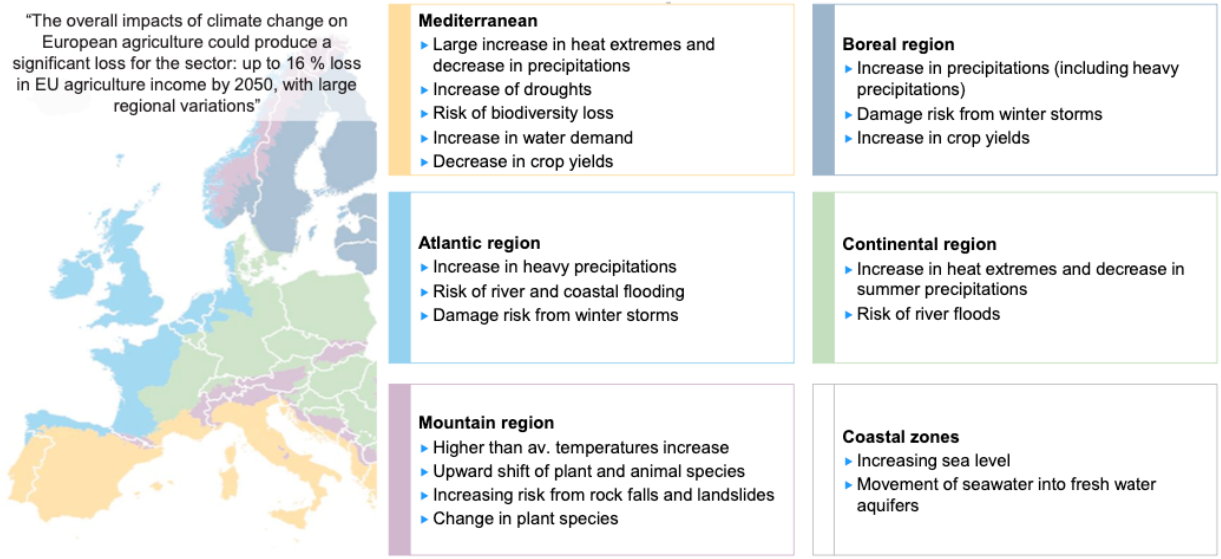

Exhibit 9 – Source: European Environment Agency[231]

Methodology summary

Our model quantifies how climate change and geopolitical shocks jointly influence Europe's macroeconomic trajectory by 2050–the common policy horizon for the EU's net zero strategy. This mid-century deadline aligns with major reference sources (NGFS[232], ADEME[233], Banque de France[234], IMF[235], European Commission[236]) and ensures a balance between analytical robustness and climate relevance: it is long enough to capture cumulative damage and transition dividends, yet short enough to remain within credible forecasting limits.

Starting from a 2024 EU27 nominal GDP baseline of €18 trillion and a neutral real growth path of +1.1% per year, potential GDP in 2050 is estimated at around €24 trillion in the absence of climate or geopolitical effects. Deviations from this baseline are then attributed to a combination of temperature-related and geopolitical variables, whose interactions define the four scenarios–Status Quo, Fragile Green, Fortress Brown, and Resilient Green–each with distinct levels of mitigation and adaptation. It is understood that this baseline will unfortunately serve as an anchor for more descriptive scenarios. At this stage, the question is: what must be done to avoid the Status Quo scenario towards which we are heading.

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[231] EEA. (2019). *Climate change adaptation in the agriculture sector in Europe*

[232] Network for Greening the Financial System. (2025). *NGFS climate scenarios for central banks and supervisors* [Report]. NGFS

[233] Agence de l'environnement et de la maîtrise de l'énergie (ADEME). (2024). *Transition(s) 2050: Pathways toward carbon neutrality* [Report]. ADEME

[234] Banque de France. (2019). *Climate change: What are the risks for the French financial sector?* Banque de France Bulletin

[235] International Monetary Fund. (2025). *Integrating climate change into macroeconomic analysis* (IMF Working Paper No. 2025/170). IMF

[236] European Commission. (2020). *A European Green Deal: Striving to be the first climate-neutral continent*. Publications Office of the European Union

Climate scenarios and inputs

The model takes as input a temperature trajectory, differentiated according to two green scenarios (the optimistic IPCC pathway SSP1-1.9) and two brown scenarios (the pessimistic pathway SSP5-8.5). Below is a reminder of the IPCC trajectories.

Table SPM.1 | Changes in global surface temperature, which are assessed based on multiple lines of evidence, for selected 20-year time periods and the five illustrative emissions scenarios considered. Temperature differences relative to the average global surface temperature of the period 1850–1900 are reported in °C. This includes the revised assessment of observed historical warming for the AR5 reference period 1986–2005, which in AR6 is higher by 0.08 [–0.01 to +0.12] °C than in AR5 (see footnote 10). Changes relative to the recent reference period 1995–2014 may be calculated approximately by subtracting 0.85°C, the best estimate of the observed warming from 1850–1900 to 1995–2014.
[Cross-Chapter Box 2.3, 4.3, 4.4, Cross-Section Box TS.1]

	Near term, 2021–2040		Mid-term, 2041–2060		Long term, 2081–2100	
Scenario	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)
SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP2-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP3-7.0	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
SSP5-8.5	1.6	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

Exhibit 10 – Source: IPCC, Summary for Policymakers.

Climate-related effects

The main effects integrated into the model are:

- The impacts on GDP quantified by A. Bilal, the OECD, and NGFS, reflecting damage and transition impacts arising from temperature increases.
- Five offsetting parameters that capture adaptation and transition dividends:
    - D1 – avoided damage (illustrative variable),
    - D2 – productivity and innovation gains,
    - D3 – social co-benefits,
    - D4 – diversification and resilience improvements,
    - D5 – natural-capital recovery.

Several complementary drivers of growth not fully covered in Bilal's framework have been integrated, such as productivity gains, job creation, social welfare effects, diversification, and trade advantages related to decarbonization. Only the first of these is fully quantified; the others are estimated relative to it, based on qualitative evidence from ADEME and IMF reports. Their quantitative influence remains moderate, but they broaden the model's scope by incorporating sources of growth typically overlooked in previous macro econometric climate assessments.

Path-dependency component

A path-dependency parameter is also introduced to reflect the structural inefficiencies associated with the *Fortress Brown* trajectory–namely, the costs of iterative, short-term adaptation strategies that later become obsolete (for instance, new coal plants that must be dismantled within two decades).

Geopolitical component

To complement the climate dimension, the model explicitly incorporates potential geopolitical disruptions transmitted through the energy and raw materials channel. These shocks are quantified using the landmark analysis of Bruegel[237] and R. Sampognaro's works[238] which estimate that a disruption comparable to the Ukraine war reduces EU GDP by around 1.4%. Using historical data and the Caldara & Iacoviello Geopolitical Risk Index (GPR), the model assumes an average arrival rate of 0.11–0.15 events per year, equivalent to about 3–4 major disruptions between 2025 and 2050–or roughly one every seven to nine years.

This corresponds to an expected 3.5 cumulative shocks by mid-century, integrated as a recurring negative adjustment to European GDP. The aggregate impact–about 1.5% of GDP by 2050, consistent with R. Sampognaro's estimations–is applied only to the two less resilient scenarios (Status Quo and Fragile Green) and annualized for simulation purposes.

Calibration and data sources

All parameters, elasticities, and calibration methods are consistent with the most recent datasets and scenario architectures from the NGFS (2025), ADEME (2024), and IMF (2025), and are cross-validated using empirical findings from Bilal & Känzig (2024) and Stern (2006).

All methodological details, including data sources, calibration tables, parameter assumptions, and derivation of each D-term, are detailed in the appendix.

[237] Pisani-Ferry. (2022). *The Economic Policy Consequences of the War*

[238] Sampognaro. R. (2022). *Guerre en Ukraine et hausse des tensions internationales : quel impact sur le PIB ?*

The four scenarios for Europe's economy

Exhibit 11 synthesizes the impact of the different scenarios on the gap between projected GDP and potential GDP in the absence of climate and shocks by 2050.

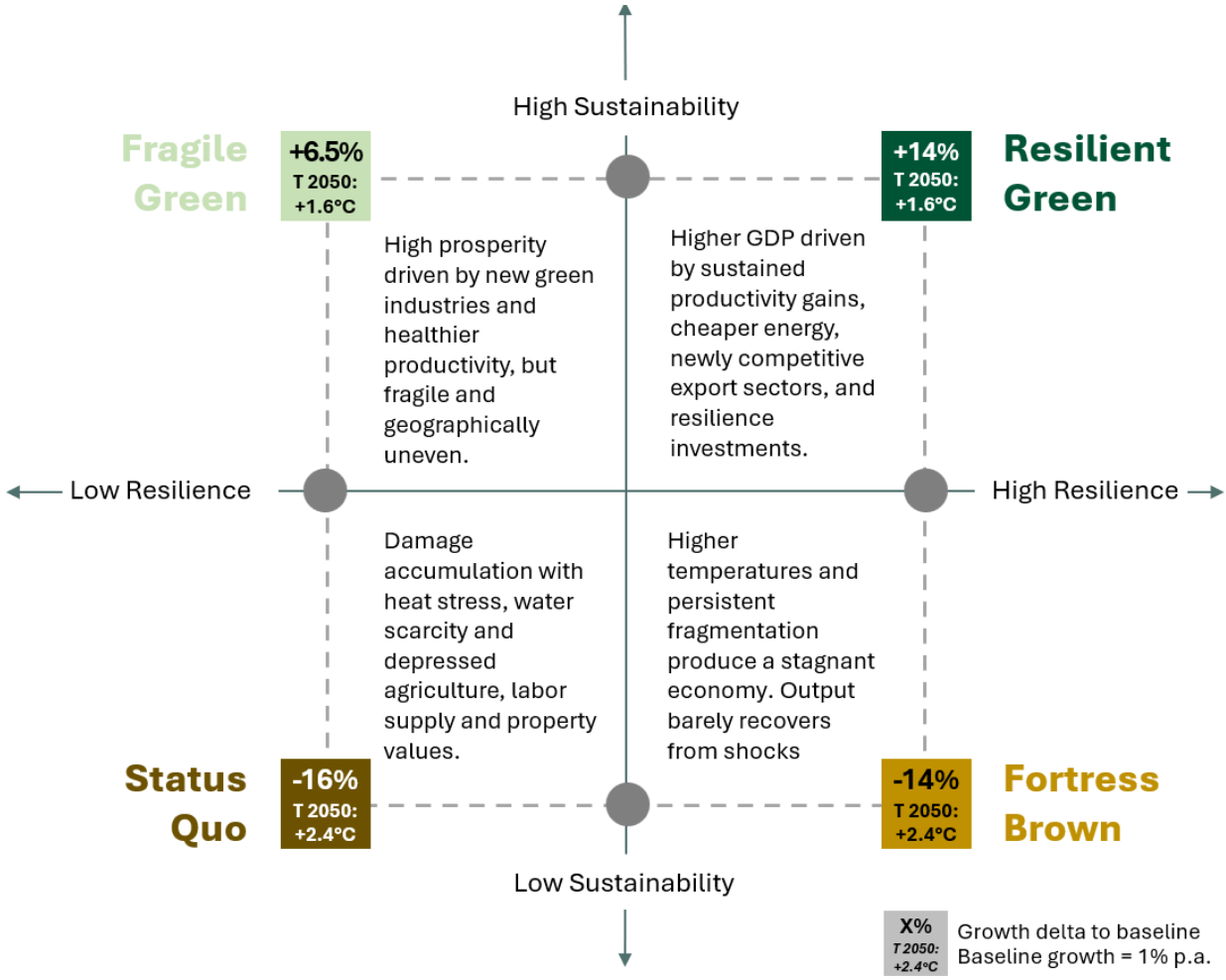

Exhibit 11 – Source: Ardabelle Capital interviews and analysis.

Scenario 1: Status Quo

ΔT = +2.4°C; Total Impact = −16% relative to baseline GDP

The Status Quo scenario represents a continuation of current trends, in which Europe fails to implement a decisive low-carbon transition. Economic growth follows its natural 1% annual path but climate impacts and recurrent geopolitical shocks erode productivity and capital. Between 2025 and 2050, cumulative temperature increases reach +2.4°C, generating compounding losses across agriculture, labor productivity, health, and infrastructure. No avoided damage or transition dividends are realized, as mitigation, adaptation, and innovation remain minimal. The macroeconomic effects are gradual but persistent: the combination of climate damage (−0.4% annually by 2050) and repeated geopolitical disruptions–assumed at 3.5 major shocks equivalent to the economic consequences of the war in Ukraine–leaves the EU economy with faint growth until 2050.

By 2050, EU GDP reaches approximately €20.1 trillion, compared with a potential output of €23.9 trillion in the absence of climate and geopolitical effects. This represents a cumulative loss of around 16% of potential GDP and establishes the counterfactual baseline against which all other transition scenarios are evaluated.

Parameter	Value	Growth vs 2024
EU GDP 2035 (€T)	18.8	4.68%
Δ T° 2035	0.39	*n.a.*
EU GDP 2050 (€T)	20.1	11.42%
Δ T° 2050	0.93	*n.a.*
Δ vs Potential	*-16%*	*n.a.*

Exhibit 12 – Source: Ardabelle Capital interviews and analysis.

Stagnation and fragmentation

By 2050, Europe finds itself confronted with an accumulation of environmental, economic, and social shocks–including recurrent heatwaves, large-scale flooding, and persistent energy disruptions–without having undertaken a decisive strategic realignment. The continent's institutional architecture fails to produce coordinated responses, and national policies remain fragmented. Diverging interests between Northern and Southern, as well as Eastern and Western member states, exacerbate political tensions and hinder collective action. As a result, public policy takes the form of an inconsistent patchwork: policy instruments differ widely between countries, collective resources are not pooled, and Europe's overall resilience remains structurally weak. Strategic infrastructure, notably ecological corridors and logistics systems, remain underdeveloped, while supply chains continue to exhibit fragility and carbon dependency. SMEs consolidate, relocate, or disappear, and no sustained investment is made in sovereignty, sustainability, or climate resilience. The cumulative effects of these trends contribute to a contraction of GDP and a marked rise in inequality.

Macroeconomic outlook: structural contraction and fiscal pressures

Economically, Europe enters a phase of structural contraction. GDP stagnates. Public and private debts reach unprecedented levels because of continuous cycles of reconstruction, emergency interventions, and crisis management. Fiscal deficits become self-perpetuating as rising social expenditures, recurrent disaster relief, and diminished tax revenues combine to stress public budgets. The financial sector becomes increasingly vulnerable, with periodic bailouts required after major climate events. Insurance markets are also destabilized: premiums rise sharply, and entire sectors eventually become "uninsurable," undermining investment and long-term planning.

Sectoral impacts: inequality, disruption, and declining productivity

Sectoral dynamics reflect deepening social and regional inequalities. Agriculture experiences a 15% decline as Mediterranean areas undergo desertification, small farms disappear, and internal migration accelerates. Production gradually shifts to less climate-affected regions, albeit at the cost of lower yields and higher structural inefficiencies. Industry suffers losses in energy-intensive and low-innovation segments such as steel and heavy chemicals, with SMEs facing acute competitive pressure, contraction of subcontracting networks, and widespread closures. Tourism and services experience profound destabilization as climate-related events erode the appeal of southern destinations, degrade cultural heritage, and disrupt transport infrastructures. Tourism-dependent SMEs, especially in southern Europe, face collapse. Investments in the energy transition remain insufficient, leaving the energy mix dominated by

fossil fuels and exposed to severe price volatility. Aging infrastructure requires costly adaptation efforts that many member states defer or address only partially.

Structural implications: the progressive erosion of SMEs

SMEs–the backbone of Europe's economic and territorial cohesion–become indicators of systemic decline. Limited access to credit, unstable supply chains, and shrinking consumer demand expose them to severe financial stress. Over the period, approximately one in four SMEs ceases operations, either through closure, absorptions by larger firms, or prolonged inactivity. Micro-enterprises outside major urban centers disappear almost entirely, accelerating regional economic desertification. Agricultural SMEs vanish most rapidly because of limited access to insurance, irrigation systems, and technical support. Industrial SMEs are increasingly absorbed into large corporate groups, leading to a concentration of subcontracting and a weakening of local innovation ecosystems. Although some specialized niches persist–such as climate-risk engineering, environmental maintenance, and crisis-management digital services–many SMEs become "zombie firms" surviving on intermittent state assistance, accumulating debt, and lacking prospects for growth or stable employment.

Europe in the world: a drift toward peripherality

On the international stage, Europe's global influence recedes markedly as most countries decide not to follow its path. Its diminished competitiveness, internal fragmentation, and chronic crisis management weaken its ability to act as a diplomatic or normative power. The continent becomes less capable of shaping global climate governance or technological standards. Its attractiveness for investment, talent, and innovation declines, and Europe increasingly resembles a "scorched capitalist zone" where reactive crisis management substitutes for long-term strategic action and inter-state cooperation.

Employment, inequality, and governance: the dynamics of decline

The scenario culminates in a significant erosion of Europe's socioeconomic fabric. Long-term unemployment rises, with the Southern and Eastern regions of Europe facing the most acute pressures. [239] Inequalities widen as territorial fragmentation intensifies and access to housing, healthcare, and education becomes increasingly uneven. Young people and low-income households bear the brunt of the instability. Rising social tensions, coupled with identity-based political radicalization, place unprecedented strain on social cohesion. Public authorities–confronted with mounting budgetary constraints–shift their focus from long-term planning to emergency management, further entrenching stagnation and fragility.

Scenario 2: Fortress Brown

ΔT = +2.4°C; Total Impact = −14% relative to baseline GDP

In the Fortress Brown scenario, Europe prioritizes security and resilience while delaying comprehensive decarbonization. Strong adaptation measures and energy security policies reduce vulnerability to some shocks, but continued reliance on fossil fuels results in high emissions and substantial physical climate damage. Productivity gains and social co-benefits are modest, and diversification and natural capital improvements provide limited relief. Path-

[239] The model does not account for the impact of AI on the job market in any scenario

dependency emerges slightly due to ongoing fossil infrastructure, which constrains long-term productivity growth.

Climate damage accumulates steadily, with GDP growing at only 0.52% per annum until 2050. Transition dividends are minimal, reflecting the lack of mitigation and innovation, so total net impacts remain predominantly negative. By 2050, European GDP reaches approximately €20.6 trillion, compared with a potential output of €23.9 trillion, missing by 14% the baseline trajectory.

This scenario illustrates that a defensive, high-security approach without coordinated decarbonization mitigates some risks but leaves Europe exposed to substantial climate-related losses, producing only limited economic gains relative to the Status Quo.

Parameter	Value	Growth vs 2024
EU GDP 2035 (€T)	19.1	5.9%
Δ T° 2035	0.39	*n.a.*
EU GDP 2050 (€T)	20.6	14.4%
Δ T° 2050	0.93	*n.a.*
Δ vs Potential	*-14%*	*n.a.*

Exhibit 14 – Source: Ardabelle Capital interviews and analysis.

Defensive sovereignty and stagnant innovation

By 2050, Europe has adopted a strategy of defensive sovereignty, turning inward to prioritize security, territorial self-reliance, and social stability over ecological or technological ambitions. Environmental objectives are largely deferred, and "green arteries" of infrastructure and logistics remain fragmented. SMEs experience significant regional divergence, benefiting only where they align with the state's protective objectives, while strategic sectors receive government support but remain poorly coordinated. Public and private investment in green innovation is minimal, resulting in inefficiencies and a slow pace of technological modernization.

Macroeconomic outlook: defensive stability and secular stagnation

Europe's macroeconomic performance is characterized by stability at the cost of dynamism. GDP barely grows at €20.6 trillion, constrained by internal barriers and protective policies that limit competition and cross-border integration. Public investment is heavily oriented toward security-related infrastructure including cybersecurity, strategic storage, and the relocalization of key production chains. Deficits are tolerated, reflecting the state's prioritization of sovereignty and protection over expansionary growth. Markets are actively managed through quotas and interventions, and inflation is controlled by regulatory mechanisms rather than market-driven adjustments. Overall, growth remains subdued, reflecting a secular stagnation that prioritizes security and predictability over innovation and expansion.

Sectoral transformations: the brown economy

Europe's productive sectors realign around national security and domestic resilience. In agriculture, production is concentrated in strategically secure areas, relying on proven technologies, cooperatives, and selective use of robotics. Export orientation declines in favor of meeting domestic consumption needs. Industrial activity experiences a partial revival fueled by national preference and sovereign policy, focusing on maintenance, defense, and equipment production. Innovation remains incremental, as industries operate largely in

isolation from international networks. Service sectors refocus on health, basic education, and public administration, while localism dominates, and mobility and trade are restricted. Supply chains are intentionally short, and the introduction of new technologies is slow and carefully vetted. In the energy sector, fossil fuels continue to dominate, with investments targeting security and relocation rather than efficiency or decarbonization.

SMEs in the fortress model: anchors of stability

SMEs that integrate into Europe's defensive framework–such as those providing maintenance, regional logistics, defense engineering, local food production, or personal services–thrive under state support. Many are family-owned enterprises with privileged access to public contracts, anchoring employment in rural and suburban areas. Innovation in these SMEs is largely incremental, aimed at maintaining established practices rather than advancing new technologies. Start-ups and export- or tech-oriented SMEs face significant regulatory and market barriers, leading to closures, pivots, or relocation abroad. Overall, the SME landscape is characterized by low penetration in high-tech sectors and a focus on conventional, security-oriented production.

Europe in the world: territorial power with declining influence

On the international stage, Europe becomes a territorial stronghold, capable of defending its model and strategic assets but increasingly disconnected from global networks of innovation, diplomacy, and climate governance. Its soft power diminishes, ceding influence in international climate policy, technological development, and global economic agendas to other major powers, such as the United States and Asia. Europe's sovereignty and self-reliance are secured, but at the cost of external relevance and engagement.

Employment, inequality, and socioeconomic dynamics

The Fortress Brown trajectory generates modest net employment growth of approximately one million jobs, concentrated in construction, maintenance, and localized production. The creation of skilled positions remains limited, constraining opportunities for younger generations. Regional inequalities deepen as large industrial and administrative centers consolidate resources while rural and peripheral areas remain marginalized. Social and professional mobility is restricted, contributing to socioeconomic stabilization but also to stagnation in social innovation and cultural participation. Tensions manifest in reduced mobility, nationalist withdrawal, and limited openness to new ideas, resulting in a society that is safe and stable but lacking dynamism and creative renewal.

Scenario 3: Fragile Green

ΔT = +1.6°C; Total Impact = +6.5% relative to baseline GDP

In the Fragile Green scenario, Europe embarks on a transition toward decarbonization, but progress is uneven and governance remains fragmented. While significant mitigation measures reduce temperature increases and avoid major physical losses, the incomplete implementation limits the full potential of technological, social, and ecological gains. Productivity benefits are moderate, social co-benefits and natural capital improvements are positive but modest, and diversification and sustainable gains partially offset climate-related

vulnerabilities. Path-dependency effects remain negligible, as the transition avoids locking in additional fossil-based infrastructure.

Climate-related damage reduces GDP by approximately −0.06% over the decades, while transition dividends–including avoided damage, productivity, social co-benefits, diversification, and natural capital–produce a net positive effect as early as 2025. Accounting for recurrent geopolitical shocks, European GDP reaches approximately €25.5 trillion by 2050, compared with a potential output of €23.9 trillion in the absence of climate impacts and shocks.

This scenario demonstrates that even an imperfect and asymmetric climate transition substantially mitigates economic losses relative to the Status Quo, reducing the cumulative GDP deviation compared to the baseline from around −16% to roughly +6.5% by mid-century.

Parameter	Value	Growth vs 2024
EU GDP 2035 (€T)	20.9	15.8%
Δ T° 2035	0.06	*n.a.*
EU GDP 2050 (€T)	25.5	41.6%
Δ T° 2050	0.13	*n.a.*
Δ vs Potential	*6.5%*	*n.a.*

Exhibit 13 – Source: Ardabelle Capital interviews and analysis.

Effective decarbonization, uncertain resilience

By 2050, Europe has succeeded in accelerating its decarbonization trajectory, yet its transition remains structurally fragile. The continent achieves significant progress in reducing emissions and embedding environmental criteria into production systems but fails to establish robust protective mechanisms against external shocks. A series of global disruptions–pandemics, large-scale cyberattacks, trade conflicts, and competition for strategic resources–exposes the vulnerability of a growth model that relies heavily on green technological innovation while remaining dependent on global supply chains. Although international coordination on decarbonization promotes the emergence of new “green arteries” governed by strict sustainability standards, Europe’s strategic exposure persists. SMEs enter global green value chains with dynamism, but their integration highlights structural dependencies that undermine resilience.

Macroeconomic outlook: constrained expansion and high volatility

Economic performance is characterized by a tension between growth and instability. GDP rises to €25.5 trillion. While deficits remain broadly contained, fiscal leeway diminishes because of the recurrent impact of supply chain disruptions and international price shocks. Financial markets become highly reactive to geopolitical developments, particularly announcements related to access to critical minerals or fluctuations in the availability of imported fourth-generation energy infrastructures. The result is an economic environment marked by cycles of overheating, inflationary pressures, and abrupt downturns, reflecting the broader volatility of global green economy flows.

Sectoral transformations: emerging clusters amid persistent dependence

Europe’s productive structures undergo significant reconfiguration. Green industries emerge as new growth centers, especially in renewable energy technologies, energy renovation, and circular-economy manufacturing. However, these sectors remain highly dependent on

imported equipment and strategic raw materials, limiting their autonomy. Agriculture adopts agroecological practices, biocontrol solutions, robotics, and water-management technologies, contributing to greener local supply chains but still retaining exposure to global disruptions. The construction sector revitalizes through large-scale renovation programs, yet successive waves of innovation create substantial inequalities among firms, with many unable to keep pace with new technological requirements. Services experience robust growth driven by digital circularity platforms, green logistics, and new environmental management activities, although the expansion of platform-based labor markets contributes to rising precarity, with many green jobs remaining temporary and poorly protected.

SMEs in the green transition: innovation, constraints, and uneven outcomes

SMEs become central actors in Europe's ecological transition, serving as laboratories for eco-design, reuse models, short-cycle production, and novel sustainable materials. Firms that adapt early thrive and are often absorbed by larger groups seeking to consolidate technological advantage. Yet even the most innovative SMEs face recurrent constraints linked to the volatility of critical inputs, the lack of resilience and the high cost of compliance with global standards. SMEs in construction, crafts, and local transport benefit intermittently from renovation programs and green urban policies, but confront unstable market conditions, fluctuating input prices, and heightened competition for skilled labor–particularly from major technology firms. Industrial SMEs, historically undercapitalized, remain structurally dependent on imported technologies and outsourced expertise. While local circular-economy activities expand, persistent bottlenecks in access to strategic materials and weak bargaining power limit the long-term viability of many SMEs. Regional inequalities intensify as innovation clusters attract investment and talent, leaving less competitive areas behind. Although public authorities deploy transition funds to mitigate disparities, only a minority of firms manage to access the full benefits of the "green deal."

Europe in the world: normative power under external constraint

Internationally, Europe asserts significant influence as a normative and technological leader in green standards, exporting decarbonization frameworks and environmental expertise. However, this leadership is constrained by its structural dependence on other geopolitical blocs for critical materials, patents, and advanced technologies. Europe's global standing oscillates between regulatory leadership and practical vulnerability, limiting its capacity to shape long-term global trajectories. The continent's influence remains real but conditional, reflecting a strategic imbalance between ambition and autonomy.

Employment, inequality, and social risks: growth with fragile foundations

The scenario results in employment growth driven by expansion in renewable energy, energy renovation, waste management, and sustainable mobility. Nevertheless, employment losses persist in sectors exposed to supply-chain volatility, such as automotive manufacturing and electronics. The digital and territorial divide remains pronounced, as peripheral regions and low-skilled workers struggle to access the training and technological resources needed to participate fully in the green economy. Skills are unable to keep pace with the rapid evolution of technologies, contributing to mismatches in labor markets. Rapid transitions generate job instability and reinforce polarization between highly qualified green-sector workers and a precarious labor force engaged in low-paid, low-protection activities. Social policies attempt to provide targeted support through training schemes and expanded safety nets, but uneven access limits their effectiveness and exacerbates existing inequalities.

Scenario 4: Resilient Green

ΔT = +1.6°C; Total Impact = +14% relative to baseline GDP

The Resilient Green scenario depicts Europe achieving a successful and coordinated low-carbon transition. Ambitious mitigation measures reduce physical climate damage, while widespread technological adoption, social co-benefits, and ecosystem recovery amplify positive economic outcomes. Diversification of the economy and improvements in natural capital further enhance resilience, and minimal path-dependency ensures that capital is not trapped in obsolete fossil infrastructure.

Climate damage is largely avoided, while productivity gains, social co-benefits, diversification, and natural capital improvements generate cumulative positive impacts. Total net impact turns positive from the outset reaching +1.62% growth annually. European GDP grows from €18.2 trillion in 2025 to €27.3 trillion in 2050, exceeding by almost 15% the projected potential GDP of €23.9 trillion.

This scenario illustrates that comprehensive climate action, combined with resilient economic planning, not only prevents losses but generates net economic dividends, positioning the EU for long-term sustainable growth.

Parameter	Value	Growth vs 2024
EU GDP 2035 (€T)	21.5	19.3%
Δ T° 2035	0.06	*n.a.*
EU GDP 2050 (€T)	27.3	51.9%
Δ T° 2050	0.13	*n.a.*
Δ vs Potential	*14%*	*n.a.*

Exhibit 15 – Source: Ardabelle Capital interviews and analysis.

Europe as a model of sovereign growth

By 2050, Europe emerges as a model of sustainable and resilient growth, having undertaken a dual revolution of green transformation and systemic resilience. The continent benefits from reinforced cooperation, pooled financial and industrial instruments, adaptive training programs, decentralized governance, and robust energy and logistics connectivity. European Union policies deliberately invest in “green arteries” such as biorefineries, electric vehicle infrastructure, and circular industries, creating integrated networks that strengthen both sovereignty and sustainability. SMEs are fully supported through digital infrastructure, public procurement, research and development funding, and collaborative innovation hubs, enabling them to contribute directly to regional and continental strategies. The benefits of the Scenario presuppose a cohesive Europe that acts as one–pooling investments, harmonizing policies, and agreeing on a common trajectory. While ambitious, this vision remains within reach if Europe chooses coordination over fragmentation.

Macroeconomic outlook: shared growth and innovation surpluses

Europe achieves unprecedented economic performance, with GDP reaching €27.3 trillion. Growth is driven by technological breakthroughs, quality upgrades in production, and the expansion of intra-European and global trade. Public finances remain sound because of the pooling of risks, the growth of coordinated European funds, and flexible taxation mechanisms. Markets operate under stable, long-term rules that promote both profitability and predictability. The combined effects of coordinated investment and structural resilience allow Europe to

achieve sustained economic expansion, reduced vulnerability to shocks, and robust fiscal health.

Sectoral transformations: Integrated value chains and circular supply systems

European productive sectors experience profound restructuring. Industry leverages fully integrated continental value chains, particularly in batteries, hydrogen, artificial intelligence, and climate engineering. Agricultural systems adopt precision technologies and biotechnologies, balancing high-quality output, food sovereignty, and export competitiveness while effectively adapting to climate challenges. Services, including digital platforms and green finance, expand significantly, benefiting from extensive training and collaborative innovation ecosystems. Energy systems achieve a 100% renewable mix, supported by smart grid integration, secure supply chains, and advances in storage and green hydrogen. Across all major sectors–energy, materials, agri-food, mobility–output and employment experience double-digit growth rates.

SMEs as engines of transformation

SMEs flourish as integral participants in Europe's resilient green economy. Public procurement, access to R&D, transition funds, and collaborative innovation hubs allow SMEs across urban, rural, and technological sectors to innovate, internationalize, and contribute to policy design. The European Innovation Bank and similar institutions provide easy access to finance and support continuous training, enabling SMEs to function as core actors in regional reindustrialization and diversification of supplier networks. Traditional business models give way to highly connected, collaborative enterprises, which form the backbone of continental green value chains and advance adoption of sustainability standards.

Europe in the world: global reference for a post-carbon model

Europe establishes itself as a global reference point for ecological sovereignty and sustainable development. It plays a leading role in international governance, exports environmental standards and adaptation methodologies, and attracts students, researchers, and capital from across the world. Cross-disciplinary innovation hubs and collaborative networks position Europe as a model for inclusive prosperity, technological leadership, and planetary-scale sustainability.

Employment, inequality, and quality of life

The Resilient Green scenario produces the highest levels of employment among the four scenarios. Skills development is extensive, reducing structural mismatches in labor markets. Inequalities decline significantly due to improved access to continuing education, professional mobility, and higher-value employment. Quality of life and social cohesion improve markedly, supported by strong social innovation and participatory governance processes. Public policies are coordinated at the European level, integrating social justice, sustainability, and economic development into a cohesive transition strategy, ensuring both prosperity and resilience. The social impacts of this scenario are also transformative. Confidence in public institutions and the social contract is high, with widespread geographic and social mobility, enhanced equality of opportunity, and improved health and job satisfaction.

Focus box: Europe's resilience leadership by design and long-term advantage

In the most favorable configuration, Europe's resilience and sustainability push does not remain an isolated effort but is progressively emulated by other major economies, so that global temperature outcomes converge toward the green trajectory Europe pioneers. This positions Europe as a first mover that sets standards, pulls others in its wake, and generates mutual benefits for partner countries and the planet through lower climate damage and more resilient value chains. It typically is what is modeled in the Resilient Green scenario.

By contrast, if Europe advances largely alone–or with only a handful of followers–global temperature outcomes would remain closer to more pessimistic IPCC scenarios, adjusted for Europe's relative weight in global emissions reduction and in the transformation of production systems. Yet even in that less cooperative world, the economic case for Europe's transition remains strong: recent work on unilateral decarbonization finds that when climate damage are measured based on global temperature shocks, the domestic cost of carbon for the EU is on the order of $216 per ton (vs. $226 in the US). This implies that, from a purely domestic cost–benefit perspective, once the upfront investment needed to cut emissions is balanced against the climate-related damage avoided, both the EU and the US can profitably decarbonize roughly four-fifths of their economic activity even if they act unilaterally. [240]

Taken together, these elements make Europe's strategic choice clear: deep decarbonization and resilience investments are justified both if others follow and if they do not, and hesitation over the direction of transformation is therefore economically misplaced.

Financing the transition

Europe faces substantial economic costs to implement a resilient transition: cumulative investments in mitigation and adaptation are estimated at 1.5-2.5% of GDP per year in the 2020s (~€250-450 billion annually), consistent across multiple assessments (EC, IEA, EIB, OECD, EEA). Front-loaded spending is economically justified, as early mitigation prevents larger, path-dependent climate damage and maximizes productivity and social co-benefits, while delayed action increases adaptation costs and GDP losses.

Estimates of Europe's climate investment needs suggest that a successful transition to net zero and resilience will require investments in the order of multiple percent of GDP annually over the coming decade. For example, the European Central Bank finds that additional green investment needs could be around €477 billion per year – approximately 2.5 % of GDP – to meet the EU's 2030 climate objectives, while earlier Commission estimates placed annual climate action investment needs around €260 billion or ~1.5 % of GDP. Other analyses suggest total climate investment needs could exceed €800 billion per year (4–5 % of GDP) when infrastructure, buildings, transport and energy are included, indicating that assumptions of investment effort in the range of 1.5–2.5 % of GDP remain within the broader policy literature.

Each scenario generates a distinct mix of mitigation and adaptation spending over time. In the Status Quo scenario, adaptation gradually dominates, pushing a large share of investment into the final decade. In the Fortress Brown scenario, reliance on fossil-based resilience similarly keeps adaptation spending above mitigation, although total investment stays relatively stable across the period. By contrast, Fragile Green and Resilient Green both allocate more to

[240] Bilal. A., Känzig. D. (2025). *Does unilateral decarbonization pay for itself?*

mitigation than to adaptation; their key difference lies in how front-loaded this effort is, with Resilient Green concentrating a larger share of adaptation spending earlier in the horizon.

Scenario	Resilience (adaptation)	Sustainability (mitigation)	Expected macro profile
Status quo	Low	Low	High damage, structural vulnerability
Fortress brown	High	Low	Security focus but high emissions → climate costs delayed
Fragile green	Low	High	Decarbonization without resilience → exposure to shocks
Resilient green leadership	High	High	Joint mitigation & adaptation → sustainable and robust growth

Exhibit 16 – Source: Ardabelle Capital interviews and analysis

Focus box: Prioritizing mitigation over adaptation

Mitigation delivers better value than a strategy that mainly absorbs physical damage and ramps up adaptation later. By mid-century, annual climate-related economic losses are projected at roughly $38 trillion, while the additional annual cost of keeping warming on a below-2°C path is estimated around $6 trillion, meaning the damage bill is several times larger than the cost of robust mitigation.[241] Each year of underinvestment in decarbonization therefore locks in future income losses that are far more expensive than the upfront transition effort. The same imbalance appears in spending needs: cumulative adaptation and resilience investments required to cope with already "committed" warming are expected to reach the tens of trillions of dollars and to overtake transition spending over time.

The underlying economics are straightforward: mitigation benefits from innovation, learning curves and economies of scale that drive down unit costs in areas such as renewables, storage and efficiency, while physical losses and the infrastructure required to protect against them become more expensive as climate risks intensify and the value of exposed assets rises.[242] Recent US figures make this concrete: around $300 billion a year is invested in clean energy, grid hardening, storage and efficiency, yet a single hurricane season with two major storms can generate $35-55 billions of insured losses, with total insured climate and weather disaster losses around $95 billion in one year and expected to rise.[243]

A narrow slice of today's physical risk in one advanced economy already consumes a large share of annual transition spending; scaled globally and over time, this reinforces the core thesis that early, decisive mitigation is financially more efficient than allowing damage and adaptation needs to accumulate and then paying a much larger bill later.

Early, well-targeted investments in mitigation and adaptation are economically efficient. Status Quo and Fortress Brown scenarios illustrate high long-term losses and path-dependency risks, while Fragile Green and especially Resilient Green demonstrate that coordinated action

[241] Potsdam Institute for Climate Impact Research. (2024).
[242] Wellington US Institutional. (2025). *Climate adaptation may cost trillions. Is your portfolio ready?*
[243] Wellington US Institutional. (2025). *Climate adaptation may cost trillions. Is your portfolio ready?*

reduces cumulative damage, enhances productivity, and can result in net GDP gains by mid-century.

Scenario	BASELINE	STATUS QUO	FORTRESS BROWN	FRAGILE GREEN	RESILIENT GREEN
EU GDP 2035 (€T)	21.2	18.8	19.1	20.9	21.5
Δ T° 2035		0.39	0.39	0.06	0.06
GDP 2050 (€T)	24	20.1	20.6	25.5	27.3
Δ T° 2050		0.93	0.93	0.13	0.13
Δ vs Baseline GDP	*0%*	*-16%*	*-14%*	*6.5%*	*14%*

Exhibit 17 – Source: Ardabelle Capital interviews and analysis.

Our analysis illustrates a fundamental feature of the ecological transition: its benefits are real, but structurally delayed. While the Resilient Green scenario is the only trajectory that generates positive cumulative GDP growth by 2050, this surplus is only fully visible beyond 2030–2035. Up to that point, the economic signals from transformative investments (in clean infrastructure, energy efficiency, hydrogen, nature-based adaptation, etc.) remain partially masked by transition frictions: industrial restructuring, capital reallocation, and labor re-skilling. This highlights a core challenge of the green transition: short-term costs are immediate, visible, and politically salient, while macroeconomic and social dividends materialize gradually. The complexity of this transition lies in its intertemporal dynamics: investments made today reshape productive capacity, energy resilience, and health outcomes over the next two decades, not overnight. The model shows that even modest delays in adaptation amplify long-run losses, as seen in the Fortress Brown and Status Quo paths, which both diverge structurally downward after 2035.

In other words, ecological transition is not just a matter of direction but of timing: the difference between action now and deferred action is not marginal; it determines whether Europe's economic trajectory bends toward resilience and surplus, or toward stagnation and compounding vulnerability.

Implications of the scenario findings

The cost of inaction is huge

In the Status Quo scenario, cumulative climate damage, resource constraints, and productivity losses reduce GDP by at least 16% relative to potential by 2050. Maintaining current policies leads to a trajectory of slow growth punctuated by increasingly severe shocks. By mid-century, GDP is projected at approximately €20.1 trillion versus a potential of €23.9 trillion. The economic contraction is structural, reflecting not only immediate physical damage but also long-term path dependencies such as fossil infrastructure lock-in and underinvestment in innovation and resilience.

Delays amplify risks and economic fragility

Time is critical. Postponing mitigation and adaptation will compound climate impacts, energy supply shocks, and geopolitical disruptions. Even modest warming produces increasing economic losses over time. The model projects almost no growth–0.42% per annum–under Status Quo conditions and 0.52% in the Fortress Brown scenario, highlighting that protectionist or fossil-heavy strategies only limit–not prevent–economic stress. Delays also increase adaptation costs disproportionately, as reactive spending on infrastructure hardening, flood

defenses, and emergency relief rises exponentially once thresholds of environmental stress are crossed.

Partial or fragmented transitions are insufficient

Intermediate scenarios–Fragile Green and Fortress Brown–demonstrate that partial efforts or uneven policies still lead to significant welfare losses. Fragile Green avoids some damage but suffers from governance fragmentation, and supply chains exposure, limiting productivity and social gains. Fortress Brown secures domestic energy and infrastructure but locks in fossil assets, raising long-term path-dependency and stranded-asset risk. In both cases, GDP remains below potential, and resilience is weaker than under a fully coordinated transition.

Path-dependency and stranded assets are critical risk factors

Scenarios with delayed or protectionist investment, notably Fortress Brown, illustrate how early choices shape long-term outcomes. Continued investment in fossil-based infrastructure locks capital into assets that may become economically obsolete or require costly retrofitting. This reduces net economic benefits, increases vulnerability to energy shocks, and limits innovation dividends. Avoiding path-dependency is essential to secure both growth and climate resilience.

Climate damage and energy-related and geopolitical shocks interact multiplicatively

The model demonstrates that climate impacts are not isolated: they amplify vulnerabilities exposed by energy import dependence and geopolitical disruptions. Even modest shocks, when interacting with physical damage, infrastructure fragility, or resource scarcity, can trigger significant GDP losses. Historical data and geopolitical risk measures (Caldara & Iacoviello, GPR) suggest these events occur every 7–9 years on average; when combined with climate-related losses, their cumulative effect is far larger than the sum of individual shocks. This underscores the need for integrated policy responses addressing both climate and energy security.

Resilient green investment can transform the economy

Only a fully coordinated, transformative transition–as modeled in the Resilient Green scenario–generates net macroeconomic gains. By front-loading mitigation spending (≈1.5 – 2.5% of GDP per year in the 2020s) and coupling it with strategic adaptation, Europe can turn climate policy from a defensive cost into a growth engine and a soft power vector. Productivity dividends avoided physical damage, and social co-benefits cumulatively increase GDP by about 14% by 2050 relative to baseline potential.

From a growth perspective, the Resilient Green path produces an upward trajectory of GDP that exceeds the “natural” potential growth path, reflecting multiple channels:

- Innovation and productivity gains through widespread diffusion of low-carbon technologies, energy efficiency measures, and digital-enabled industrial upgrades.
- Energy and resource security dividends, as investments in renewables, storage, and hydrogen reduce import dependency and volatility.
- Social co-benefits, including lower health costs from reduced pollution, and enhanced labor productivity.

Taken together, these elements make Europe's strategic choice clear: deep decarbonization and resilience investments are justified both if others follow and if they do not, and hesitation over the direction of transformation is therefore economically misplaced.

European GDP in 2050 across four scenarios vs. €24T GDP 2050 baseline[244]

Exhibit 18.1 – Source: Ardabelle Capital interviews and analysis.

[244] As detailed in the methodology of the model, baseline GDP growth is set at 1% annually (average between IMF, OECD, ADEME, European Commission, NGFS and Banque de France data), from €18T in 2024 to €24T in 2050

GDP variation across the four scenarios

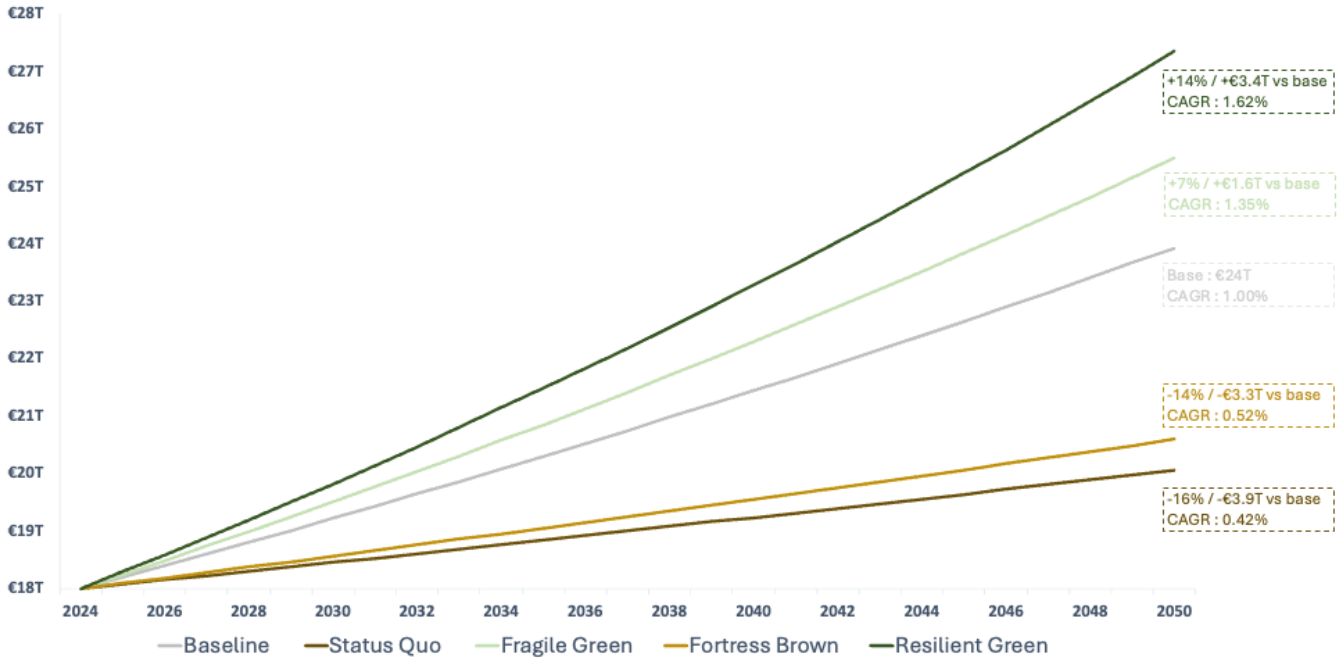

Exhibit 18.2 – Source: Ardabelle Capital interviews and analysis.

These graphs of GDP trajectories highlight that Fragile Green and Resilient Green are the only scenario that do not just avoid losses but actively generates surplus growth, illustrating that climate action is not only a defensive strategy but a proactive economic one. The Resilient Green scenario clearly underlines the extent of all the upside that could be captured by Europe, if it filled all its resilience, sustainability and sovereignty goals. The positive impacts of this transition take longer to materialize, whereas the negative effects of inaction appear much more rapidly.

Front-loading mitigation reduces long-term costs

The scenarios illustrate a clear non-linear relationship between early mitigation investment and cumulative economic losses. Investing heavily in the 2020s–as in Resilient Green–yields avoided climate damage, lower energy costs, and productivity dividends that compound over decades. By contrast, delaying action, even by a decade, forces higher adaptation spending later, often at lower efficiency and higher unit cost. For example, in Status Quo and Fortress Brown, adaptation costs escalate sharply after 2040 as reactive spending responds to accumulated shocks, highlighting the principle: “spend early to save more later.”

Investment in innovation and productivity acts as a structural multiplier

Coordinated transitions generate endogenous growth effects beyond avoided damage. In Resilient Green, GDP gains arise from:

a. Diffusion of low-carbon technologies (renewables, storage, hydrogen) which reduces energy costs and dependency.
b. Industrial modernization and digitalization, boosting labor and capital productivity.

c. Spillover effects from R&D and IPCEI-supported projects, strengthening EU competitiveness in strategic sectors.

The cumulative effect is that climate policy transforms from a defensive measure into a growth engine, with GDP exceeding the "natural" growth path by mid-century.

Nature-based and targeted adaptation delivers cost-effective resilience

Strategic adaptation measures–particularly ecosystem restoration, flood management, and targeted health interventions–achieve higher cost-efficiency than blanket hard infrastructure spending. The Resilient Green scenario shows that combining nature-based solutions with targeted hardening reduces long-term adaptation needs by leveraging ecosystem services, maintaining social resilience, and avoiding stranded infrastructure investments.

Economic gains from coordinated transitions exceed direct climate cost savings

Resilient Green demonstrates that macroeconomic gains are not solely the result of avoided damage. Productivity improvements, lower energy costs, and social co-benefits cumulatively generate additional GDP growth, highlighting that climate action can be a net positive investment rather than a pure cost. This reframes the debate: the transition is an opportunity to reshape the EU economy for long-term prosperity.

Timing, scale, and coordination matter more than total spending alone

All scenarios indicate that the efficacy of climate and adaptation investments depends on when, where, and how funds are deployed. Spending similar amounts under fragmented governance (Fragile Green) produces weaker economic outcomes than front-loaded, coordinated spending (Resilient Green). This suggests that institutional capacity, policy coherence, and long-term planning are as critical as financial volume in determining economic outcomes.

Comparison to other scenario-based research papers

Our scenarios account for elements we consider crucial; however, as models, they cannot be exhaustive. Other organizations, such as ADEME[245], make different trade-offs in their approaches, for instance placing greater emphasis on frugality when building their models.

Conclusion

Redefining the Status Quo scenario as a more realistic baseline

The €23.9 trillion baseline GDP projection for 2050 reflects conventional economic modeling that treats climate damage and geopolitical disruptions as exogenous shocks rather than endogenous structural forces. This framing assumes a stable macroeconomic environment in which growth proceeds along its natural path, interrupted only by temporary external disturbances. **Yet this assumption no longer holds**.

[245] ADEME. (2021). Les scénarios 2050

Given Europe's current emissions trajectory and exposure to recurring supply-chain shocks, the Status Quo scenario represents now the most plausible continuation of present policies and behaviors. **In this light, the Status Quo trajectory**, which projects GDP of approximately €20.1 trillion by 2050, **should serve as the relevant baseline** for policy evaluation. Comparing alternative scenarios against this realistic projection rather than an idealized potential clarifies the true economic stakes of inaction and reframes the transition scenarios not as costs relative to an unattainable optimum, but as gains relative to a deteriorating default path.

Using this new baseline, the differences between scenarios become much steeper, with up to 36% difference in EU GDP by 2050 between the most optimistic scenario–Resilient Green–and the newly defined baseline.

Scenario	STATUS QUO - NEW BASELINE	FORTRESS BROWN	FRAGILE GREEN	RESILIENT GREEN
EU GDP 2035 (€T)	18.8	19.1	20.9	21.5
Δ T° 2035	0.39	0.39	0.06	0.06
GDP 2050 (€T)	20.1	20.6	25.5	27.3
Δ T° 2050	0.93	0.93	0.13	0.13
Δ vs New Baseline GDP	*n.a.*	*+3%*	*+27%*	*+36%*

Exhibit 18.3 – Source: Ardabelle Capital interviews and analysis.

European 2050 GDP across 3 scenarios vs newly defined Status Quo-baseline

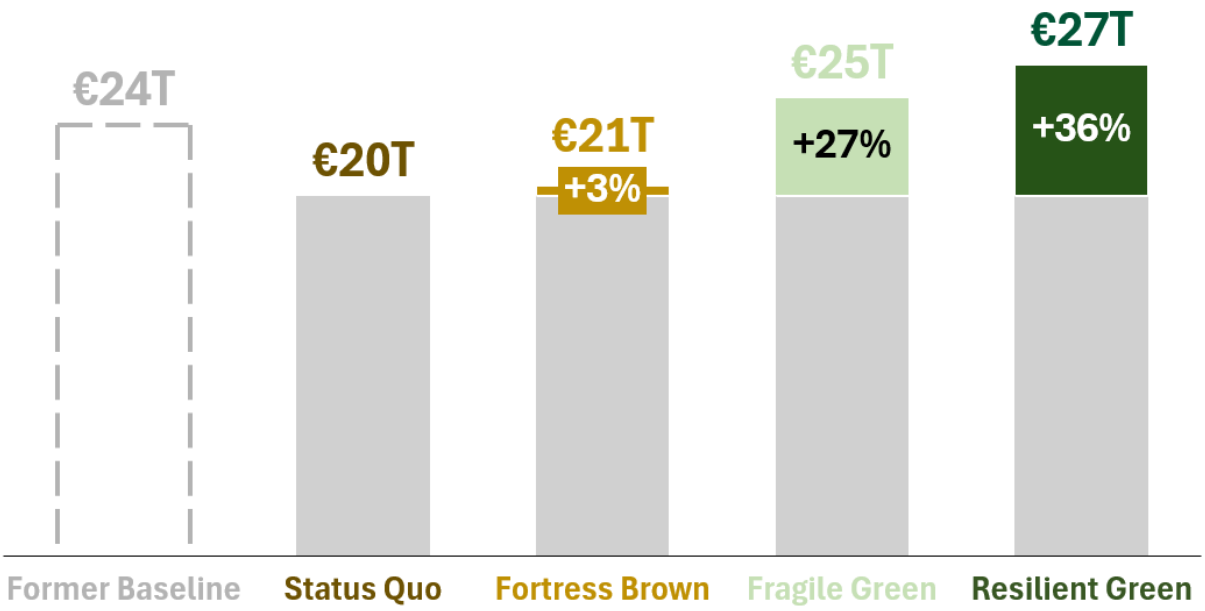

Exhibit 18.4 – Source: Ardabelle Capital interviews and analysis.

Estimating the return on investment (ROI) of the Resilient Green scenario

Allocating 2% of GDP[246] annually from 2025 to 2030 to remain on the below 2°C pathway establishes the foundation for the Resilient Green scenario. Frontloading these investments maximizes long-term returns, as early capital deployment generates strong multiplier effects in subsequent decades. Based on these assumptions, the admittedly imprecise but directionally accurate ROI of this investment–approximately €350-400 billion per year–amounts to 318%.[247] In other words, every €1 invested to maintain the temperature trajectory is projected to yield €3.18 in return (€1 recovered plus €2.18 gained). This directional outcome aligns with findings from the McKinsey Global Institute, which estimates that the benefits of investments aimed at protecting populations from climate hazards could exceed costs by roughly sevenfold,[248] and from the Climate Change Committee (estimating that benefits exceed costs by 2.2 to 4.1 factor).[249]

[246] Consistent with centrale estimates in recent literature
[247] Using the newly defined baseline
[248] McKinsey Global Institute. (2025). *Climate adaptation more than covers its cost*
[249] Climate Change Committee. (2026). *Supplementary analysis of the Seventh Carbon Budget*

5. A roadmap for a resilient and sustainable Europe

Achieving a resilient and sustainable European economy requires a coherent strategy that reinforces existing EU instruments while addressing current policy gaps. Europe's recent crises have revealed structural vulnerabilities–geopolitical dependencies, fragmented industrial capabilities, and insufficient adaptation investment–that cannot be resolved through incremental changes alone. We conclude this reflection with recommendations for concrete measures aimed at enhancing the effectiveness of current frameworks and accelerating the continent's transition toward strategic autonomy and long-term stability. The recommendations are aimed at financial actors, corporate and industry leaders, European and national governments, and citizens and civic institutions**.** We do not claim that these recommendations are especially new or disruptive: many of them have been advocated for years. And we aim at praising these efforts and accompanying them. However, we believe that we are shedding new light on them, combining our quantitative economic evidence and our sharp focus on resilience, sustainability and sovereignty.

Summary of our recommendations

Stakeholder	Priority area	Core recommendation
Financial Actors	Green & resilient infrastructure	Prioritize infrastructure investments that reduce systemic risk
	Make adaptation investable	Scale credible and bankable climate adaptation investments
	Insurance market resilience	Preserve insurability amid rising climate-related losses
Corporates & Industry Leaders	Bottom-up value chain resilience	Build multi-tier supply-chain visibility and risk management
	Scope 3 transformation	Make Scope 3 emissions reduction a core decarbonization and resilience strategy
	Resilience as competitive advantage	Use governance and disclosure to turn resilience into strategic differentiation
European & National Governments	European Industrial Resilience Pact	Establish an EU-wide framework for continuous monitoring and industrial capacity-building
	Localized & diversify supply chains	Reduce strategic dependencies through targeted reshoring, nearshoring, and diversification
	Trade, competition & energy policy	Embed resilience objectives into State aid, trade, and energy infrastructure policy
	Regulatory consistency	Uphold the ambition of Europe's regulatory and financial commitments
Citizens & Civic Institutions	Transparency & accountability	Strengthen accountability through access to sustainability and product data
	Culture of long-term value	Promote sustainability, skills, and innovation through education and civic engagement
	Community-level resilience	Build local adaptive capacity to climate and supply-chain shocks
	Territorial resilience	Advance place-based development and multi-level climate governance

Exhibit 19 – Source: Ardabelle Capital interviews and analysis.

Recommendations for financial actors

Prioritize green and resilient infrastructure

Financial institutions should expand their use of innovative instruments — resilience bonds, catastrophe bonds, and blended finance facilities — to direct capital toward infrastructure that reduces systemic exposure to climate and geopolitical risks. Where relevant, these strategies can be aligned with the Sustainable Finance Disclosure Regulation (SFDR) to enhance transparency toward investors.

Precedents already exist. The issuance of green and sustainability-linked bonds tied to infrastructure resilience–such as flood protection, grid reinforcement, and climate-resilient transport–has grown rapidly, with several EU Member States and municipalities successfully attracting institutional capital at favorable rates.[250] Infrastructure priorities should include renewable energy expansion, grid modernization, battery and hydrogen storage, sustainable mobility, and circular economy infrastructure, all of which reduce systemic exposure to energy price volatility and physical climate risks.

The European Investment Bank has played a catalytic role by offering favorable lending terms, risk-sharing instruments, and project preparation support for high-resilience infrastructure, helping to crowd in private capital for projects that might otherwise be perceived as too risky or capital-intensive.[251]

Make climate adaptation investable

Climate adaptation remains chronically underfunded despite the availability of increasingly concrete risk data and classification tools. Financial institutions should integrate physical climate risk assessments into lending and underwriting models, and actively deploy capital into adaptation projects, coastal protection, water management, and supply-chain resilience infrastructure, rather than waiting for classification frameworks to mature further.

Some banks and insurers have already begun incorporating location-specific climate risk data into credit decisions for infrastructure, agriculture, and real estate projects, adjusting pricing and maturities accordingly.[252] Public-private partnerships can then mobilize capital at scale for adaptation projects such as coastal protection, water management, biodiversity restoration, and supply-chain resilience infrastructure. The Dutch Delta Program and similar flood protection schemes demonstrate how long-term public commitment can crowd in private finance for adaptation investments with high social returns.[253]

Corporate coalitions must extend beyond industry peers to include financial actors. Specialized funds and financial stakeholders are decisive enablers of this transition: as capital allocators with a deep understanding of what is at stake, they are uniquely positioned to direct

[250] European Investment Bank. (2023). *EIB Group Climate Bank Roadmap 2021–2025: Progress report*. European Investment Bank.
[251] European Investment Bank. (2022). *Financing climate resilience and adaptation*. European Investment Bank
[252] Network for Greening the Financial System. (2023). *Climate-related financial risks: Measurement methodologies*. NGFS
[253] Organization for Economic Co-operation and Development. (2021). *Financing climate adaptation: Improving economic efficiency of public spending*. OECD

resources where they matter most: towards the European SMEs that are the true engines of change.

Reinforce insurance market resilience

Europe's insurance sector faces increasing stress as climate-related losses intensify, threatening coverage availability in high-risk regions. To maintain insurability, insurers should develop innovative products such as parametric insurance for SMEs, micro-insurance schemes for vulnerable regions, and blended-risk pools co-financed by governments.

Parametric insurance pilots in agriculture and renewable energy–where payouts are triggered by predefined weather thresholds rather than assessed damages–have already reduced administrative costs and improved liquidity for affected firms. Collaboration with regulators will be essential to adapt solvency frameworks and prevent market withdrawal from exposed areas.

Public-private reinsurance mechanisms, like those used for terrorism or natural catastrophe risks in countries such as France and Spain, may be required to preserve insurance coverage and financial stability in climate-exposed regions. Without such mechanisms, escalating uninsured losses could undermine both economic resilience and social cohesion.

Recommendations for business and industry leaders

Build resilient value chains from the bottom up

Firms should operationalize resilience by mapping their supply chains beyond Tier 1 suppliers and establishing explicit diversification thresholds for critical inputs: rare earths, lithium, semiconductors, ammonia, and pharmaceutical precursors. Structured risk assessment methodologies consistent with EU due diligence standards can support this effort, providing a framework for identifying and addressing upstream vulnerabilities. Many enterprises currently map only Tier 1 suppliers, yet recent disruptions have demonstrated that the most acute vulnerabilities often arise further upstream. The 2021–2022 semiconductor shortage, for example, revealed that automotive manufacturers were exposed not only to direct chip suppliers but to concentrated production of specific lithography equipment and specialty gases several tiers upstream.[254]

Leading firms have begun to address this gap by deploying advanced tracing and supplier-mapping tools. Companies such as BMW and Volkswagen have piloted blockchain-based and cloud-enabled platforms to trace cobalt and lithium supply chains beyond Tier 2, improving both risk visibility and compliance with due-diligence requirements.[255] Similar multi-tier mapping initiatives are being adopted in pharmaceuticals, where shortages of basic inputs during the Covid-19 crisis exposed Europe's reliance on geographically concentrated API producers.

Procurement strategies should therefore formalize these thresholds, ensuring that no single supplier or region exceeds a defined dependency ratio for any critical input. Some energy-intensive firms have already introduced internal "dependency caps" following the 2022 gas crisis, limiting exposure to single-country energy or feedstock sources and embedding

[254] OECD. (2023). *Supply chain resilience: Policy perspectives*
[255] European Commission. (2023a). *Due diligence and raw material traceability initiatives*

diversification into supplier scorecards.[256] Firms can further enhance preparedness by conducting climate and geopolitical stress tests aligned with the Task Force on Climate-Related Financial Disclosures (TCFD), integrating results into contingency planning and capital allocation decisions. Multinationals in the chemical and food sectors have begun to simulate extreme weather and trade-disruption scenarios to assess impacts on logistics routes, inventory buffers, and supplier solvency. The use of digital twins, predictive analytics, and collaborative supplier platforms–such as SAP Ariba and Catena-X–has already demonstrated measurable improvements in early-warning capabilities and crisis response times across complex value chains.

Lead by transforming Scope 3 emissions

Achieving the EU's 2030 climate targets requires substantial reductions in Scope 3 emissions, which account for over 70% of total emissions in sectors such as construction, food, and consumer goods. Corporations should prioritize supplier engagement programs that combine emissions monitoring, technology adoption, and capacity-building in lower tiers of the supply chain — embedding decarbonization requirements directly into procurement and contracting rather than treating them as a parallel reporting exercise.

Several large firms already illustrate the effectiveness of this approach. For example, Unilever and Nestlé have implemented supplier climate programs that combine emissions data sharing, preferential contracting, and technical assistance for small producers, leading to measurable emissions reductions while improving supplier resilience and productivity.[257] In heavy industry, companies such as Volvo Group and ArcelorMittal have integrated carbon-reduction targets directly into supplier contracts, incentivizing the use of low-carbon steel and circular materials.[258] Corporations can accelerate progress by embedding circular design principles into product development, extending product life through remanufacturing, repair, and adopting carbon-adjusted pricing mechanisms within procurement. The automotive and machinery sectors offer concrete examples: remanufacturing programs at firms such as Renault and Caterpillar have reduced material demand, lowered Scope 3 emissions, and increased supply security for critical components.

Participation in sectoral coalitions can enable cross-company coordination, reduce fragmentation in data standards, and de-risk early investments in low-carbon technologies and circular systems Examples span multiple industries and value chains: the EU Circular Plastics Alliance brings together over 275 organizations across the full plastics value chain, from producers and converters to recyclers and public authorities, with a binding commitment to scale recycled plastics use to 10 million tonnes annually in Europe;[259] VinylPlus has demonstrated that long-term voluntary commitments structured around verifiable recycling targets can deliver measurable circularity gains at the European industrial scale, having recycled over 9.5 million tonnes of PVC since 2000;[260] and FoodDrinkEurope's net-zero roadmap has provided a sector-wide decarbonization pathway for European food and drink manufacturers, coordinating action on energy efficiency, packaging, and supply-chain

[256] International Energy Agency. (2023). *Energy supply security and clean energy transitions*
[257] Science Based Targets initiative (SBTi). (2023). *Engaging Supply Chains on the Decarbonization Journey: Supplier Engagement Guidance*
[258] International Energy Agency. (2023). *Energy supply security and clean energy transitions*
[259] European Commission. (2019). Circular Plastics Alliance Declaration. Brussels: European Commission
[260] VinylPlus. (2024). Progress Report 2024. Brussels: VinylPlus

emissions.[261] In industrial decarbonization, initiatives such as the Clean Hydrogen Partnership, the First Movers Coalition and the Alliance for Zero-Emission Aviation aggregate demand and accelerate deployment of emerging technologies that would be too risky for individual firms to pursue alone. These coalitions have demonstrated their value by creating shared standards, pooling capital, and building ecosystem-wide capacity for transformation.

Turn resilience into a competitive edge

Firms that embed resilience into their core strategy are increasingly rewarded by markets and regulators alike.

Empirical evidence suggests that firms with advanced climate and supply-chain risk management benefit from lower cost of capital and improved creditworthiness. Rating agencies such as Moody's and S&P have begun explicitly incorporating exposure to climate and supply-chain disruptions into credit assessments, particularly in energy-intensive and globally integrated sectors.[262] Similarly, insurers are increasingly differentiating premiums based on firms' adaptation and risk-mitigation measures, rewarding proactive resilience planning.

Embedding resilience at the governance level–through dedicated resilience or risk officers, board-level oversight, or cross-functional steering committees–can help align operational decisions with long-term strategic objectives. Firms that have adopted such structures, particularly in the energy and logistics sectors, report faster response times during crises and greater investor confidence. Beyond risk mitigation, resilience can thus become a source of strategic differentiation, enhancing attractiveness to customers, employees, and long-term investors.

While reporting expectations have been scaled back, most notably through the Omnibus simplification of the Corporate Sustainability Reporting Directive (CSRD) and the reduced scope of the Corporate Sustainability Due Diligence Directive (CS3D), these regulations remain useful instruments to communicate resilience to investors, insurers, and business partners, and should not be reduced to mere compliance exercises.

Recommendations for European and national governments

Create a European Industrial Resilience Pact

A European Industrial Resilience Pact can serve as a unifying policy framework that consolidates and strengthens existing initiatives such as the Green Deal Industrial Plan, the Net-Zero Industry Act (NZIA), and the Critical Raw Materials Act (CRMA). While these instruments provide important direction, they currently lack a dedicated structure for continuous risk monitoring and capacity-building. The resilience pact should therefore mandate regular supply chain stress tests aligned with the Commission's Single Market Emergency Instrument (SMEI), extending them to additional sectors where vulnerabilities persist–most notably agri-food inputs, pharmaceutical precursors, renewable components, and advanced materials.

[261] FoodDrinkEurope & Ricardo Energy and Environment. (2021). Decarbonization Roadmap for the European Food and Drink Manufacturing Sector. Brussels: FoodDrinkEurope

[262] Moody's Investors Service. (2023). *Environmental, social and governance risks: How climate and supply-chain risks affect credit quality*. Moody's

Some precedents already illustrate the feasibility and necessity of such an approach. During the Covid-19 pandemic, ad hoc stress testing of pharmaceutical supply chains revealed Europe's heavy dependence on active pharmaceutical ingredients (APIs) sourced from China and India, prompting the Commission to launch targeted initiatives to reshore selected API production.[263] Similarly, the semiconductor shortages of 2021–2022 exposed structural weaknesses in Europe's access to advanced chips. This directly motivated the European Chips Act and its emphasis on capacity mapping and early-warning indicators.[264] Embedding such assessments permanently within a resilience pact would institutionalize lessons learned from these crises rather than treating them as exceptional events.

In parallel, early-warning mechanisms can be put in place by expanding the competencies of the European Raw Materials Alliance (ERMA) and by establishing a central resilience observatory within the Commission. ERMA's work on rare earths–particularly its identification of supply bottlenecks in permanent magnets used in wind turbines and electric vehicles–demonstrates the value of coordinated industrial intelligence. Strategic stockpiling efforts, currently fragmented at the national level, require harmonization and should be coordinated through joint procurement mechanisms similar to those used during the Covid-19 vaccine rollout, which successfully pooled demand, reduced price volatility, and strengthened negotiating power vis-à-vis global suppliers.[265]

Financing for industrial capacity–particularly in semiconductors, batteries, and hydrogen–can be strengthened by extending the scope of Important Projects of Common European Interest (IPCEIs) and by increasing the risk-bearing capacity of InvestEU and the European Investment Bank. Existing IPCEIs on batteries and hydrogen have already mobilized more than €20 billion in combined public and private investment, supporting cross-border value chains and reducing first-mover risks in capital-intensive sectors.[266]

Localize and diversify strategic supply chains

Resilience requires a more targeted approach to reshoring, nearshoring, and diversification than is currently embedded in EU policy. While the NZIA establishes production benchmarks for clean technologies, its transformative potential remains constrained in the absence of explicit incentives for firms to relocate bottlenecked segments of their value chains to Europe or to trusted neighboring economies. Evidence from the battery sector illustrates this gap: despite strong demand growth, Europe remains heavily reliant on imported cathode materials and refined lithium, largely due to investment uncertainty and lengthy permitting processes.[267]

To address this gap, governments could link public procurement rules to resilience criteria, rewarding suppliers with diversified sourcing portfolios or regional production footprints. France's use of resilience-oriented procurement criteria in selected health-sector tenders–prioritizing suppliers with European manufacturing capacity for critical medicines–provides a concrete national example of how procurement can reinforce supply security without breaching Single Market rules.[268] Introducing regional diversification incentives–such as targeted tax credits, preferential procurement treatment, and resilience scoring systems–would further discourage overdependence on single suppliers or geographies. In parallel, the

[263] European Commission. (2020). Pharmaceutical Strategy for Europe.
[264] European Commission. (2021a). European Raw Materials Alliance Action Plan
[265] European Court of Auditors. (2022). EU vaccine procurement during COVID-19
[266] European Commission. (2022b). State of play on IPCEIs
[267] International Energy Agency. (2023). *Global supply chains for clean energy technologies*
[268] OECD. (2023) *Public procurement and supply chain resilience*

state aid framework could be revised to allow time-limited support for relocation in sectors where systemic dependencies have been clearly identified. This was allowed under the Temporary Crisis and Transition Framework following Russia's invasion of Ukraine.[269] More broadly, these efforts call for a deliberate recentering of strategic choices around Europe: reducing dependencies on external energy sources and critical raw materials strengthens both economic resilience and strategic autonomy, and where investment incentives and industrial policy can be oriented toward circular materials, recycled content, and European energy infrastructure, the resilience dividend that a European option delivers warrants giving it greater weight in strategic decision-making.

Strengthening the Critical Raw Materials Act is equally important. This requires clearer and more predictable investment incentives for extraction, refining, and recycling within Europe, alongside accelerated permitting and improved planning certainty. At the territorial level, the EU could benefit from promoting industrial clusters and cross-border value-chain hubs–such as the emerging battery valleys in Spain and Central Europe–by mobilizing cohesion funds and the Just Transition Mechanism to anchor new manufacturing capacities and supplier networks in structurally weaker regions.

Finally, diversification toward non-traditional but reliable partners–such as Canada, Australia, and selected African economies–could be fostered through long-term offtake agreements, investment guarantees under EFSD+, and support for joint industrial projects. The EU-Canada Strategic Partnership on Raw Materials, signed in 2021, provides a concrete template for combining trade, sustainability standards, and industrial cooperation to reinforce supply security.

Embed resilience into trade, competition, and energy policy

It would be beneficial for competition policy, traditionally centered on preventing market distortions, to evolve to reflect Europe's broader pursuit of strategic autonomy and supply-chain security. While the recent revisions of the State Aid Temporary Crisis and Transition Framework mark an initial shift, a more structural transformation could lead the change. Embedding resilience-based thresholds into state aid rules would allow the Commission to authorize targeted support for critical technologies and infrastructures whose absence poses systemic risks, without undermining the integrity of the Single Market. The Commission's approval of large-scale hydrogen IPCEIs, despite their high concentration of public support, illustrates how competition rules can already accommodate resilience objectives under clearly defined conditions.[270]

In parallel, it may be desirable for competition policy to be more closely aligned with resilience objectives, for example by allowing–and, where appropriate, encouraging–strategic alliances, joint ventures, and shared intellectual-property platforms in sectors essential for the green and digital transitions. The Important Project of Common European Interest on Microelectronics, which enabled cooperation among firms across multiple Member States, demonstrates how such arrangements can strengthen technological sovereignty while preserving competitive dynamics.

Trade policy can also help to advance these aims, for example by integrating secure and sustainable value-chain provisions into ongoing negotiations with partners such as the United States and key Indo-Pacific economies. The EU-US Trade and Technology Council already

[269] European Commission. (2022c). *Temporary Crisis and Transition Framework*
[270] European Commission. (2022d). *Hydrogen IPCEIs: Commission decisions*

provides a forum for coordination on semiconductor supply chains and export controls, highlighting how trade governance can support resilience objectives beyond tariff reduction.[271] Finally, energy autonomy remains a precondition for industrial resilience: the EU should accelerate the deployment of cross-border energy infrastructure by fast-tracking Projects of Common Interest in hydrogen corridors, offshore renewable grids, biomethane networks, and electricity interconnection capacity. Streamlining permitting procedures under the Renewable Energy Directive and coordinating national investment plans would further support regional diversification and reduce dependency on volatile external energy sources, as evidenced by the rapid expansion of LNG and renewable infrastructure following the 2022 energy crisis (IEA, 2023).

Uphold the ambition of Europe's regulatory and financial commitments

Europe's regulatory landscape has evolved significantly in recent years. Regulations been scaled back, narrowing their scope and reducing the number of companies subject to mandatory disclosure. While this simplification reflects a legitimate concern for administrative burden, it should not be read as a signal of regulatory retreat — nor should it obscure the depth and breadth of the binding framework that remains in place.

The deeper drivers of Europe's green transition are the coercive instruments and large-scale financing mechanisms that continue to operate — and in several cases, to tighten. The EU Emissions Trading System (EU ETS) and its Carbon Border Adjustment Mechanism (CBAM) place a real and rising price on carbon. The Renewable Energy Directive (RED I/II/III), the Packaging and Packaging Waste Regulation (PPWR), the Waste Framework Directive, and the Water Framework Directive impose concrete operational obligations across sectors. At the financing level, the Green Deal investment packages, InvestEU, and the European Investment Bank continue to mobilize capital at scale. Maintaining the ambition and integrity of these instruments — resisting the temptation to treat simplification as an opportunity for broader rollback — is the precondition for all that follows.

Recommendations for citizens and civic institutions

Demand transparency and responsibility

Citizens and civil society actors play a crucial role in reinforcing accountability across value chains and public policy. Greater transparency can be achieved through civil society's active use of sustainability data made available under existing and forthcoming disclosure frameworks — including, where applicable, data generated under the CSRD and the Digital Product Passport (DPP). While the scope of these regulations has been narrowed by the Omnibus simplification, the data they generate remains a meaningful tool for NGOs, consumer organizations, and trade unions to scrutinize corporate claims and reduce the scope for greenwashing.).

Several examples already demonstrate the potential of transparency-driven accountability. Civil society organizations have used mandatory non-financial disclosures under the Non-Financial Reporting Directive (NFRD)–the predecessor to CSRD–to challenge misleading environmental claims in sectors such as fashion and agri-food, prompting enforcement actions

[271] Bradford, A. (2023). *The Brussels Effect Strikes Back: How the European Union Exported Its Regulatory Power in the Age of Economic Security*

and reputational consequences for firms.[272] Similarly, product-level transparency initiatives, such as energy labelling and food-origin labelling, have measurably shifted consumer demand toward more efficient and locally sourced products, reinforcing regulatory objectives through market behavior.

Consumer choices that favor low-carbon, durable, locally produced, and circular goods can therefore act as a complementary governance mechanism. When aggregated at scale, such behavior sends credible market signals that encourage firms to invest in resilient and sustainable production models, particularly when combined with organized civil society monitoring and strategic litigation.

Promote a culture of long-term value

Europe's long-term competitiveness depends not only on policy and investment, but also on a societal culture that values sustainability, adaptation, and technological innovation. Educational institutions play a central role in shaping this culture. Integrating climate science, digital literacy, and circular economy principles into primary, secondary, and tertiary education has been shown to improve awareness of systemic risks and increase acceptance of long-term policy trade-offs.[273]

Vocational education and training systems are equally critical. As electrification, automation, and renewable energy deployment accelerate, skills mismatches risk becoming a bottleneck for both resilience and competitiveness. Programs supported by the European Skills Agenda and Erasmus+–including reskilling initiatives for construction workers, energy technicians, and manufacturing operators–illustrate how education policy can directly support the green and resilient transition.[274]

Civic organizations also contribute to resilience by fostering local experimentation and social innovation. Initiatives such as energy cooperatives, repair cafés, community-supported agriculture, and participatory climate planning processes have expanded rapidly across Europe, strengthening social capital while reducing material and energy dependencies.[275] Political engagement that supports evidence-based policymaking–through informed voting, public consultations, and structured dialogue with institutions–is essential for sustaining public legitimacy during periods of structural transformation, particularly when short-term adjustment costs are unavoidable.

Foster societal resilience through community-level adaptation capacity

Societal resilience increasingly depends on the ability of local communities to anticipate, absorb, and recover from climate- and supply-related shocks. Citizens organizations, municipalities, and civil society networks are often the first responders during crises, yet they remain under-resourced relative to their role. Supporting these actors in developing local resilience plans–covering energy autonomy, circular-economy initiatives, food security, and emergency preparedness–is therefore a strategic investment.

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[272] European Commission. (2023).
[273] UNESCO. (2021). *Education for sustainable development: A roadmap*
[274] European Commission. (2022)
[275] European Environment Agency. (2023).*Conditions and pathways for sustainable and circular consumption in Europe*

Community energy projects, including local solar cooperatives and district heating networks, have improved energy affordability and security in rural and peri-urban areas while reducing exposure to volatile fossil fuel markets.[276] During recent climate extremes, municipalities with established local food systems and mutual-aid networks demonstrated faster recovery and lower social disruption than those reliant on long-distance supply chains.[277]

The EU and Member States can scale such efforts by expanding funding through programs such as LIFE, Horizon Europe, and the Social Climate Fund. Horizon Europe missions on climate adaptation already support citizen-led innovation labs and living labs that co-design solutions with local stakeholders, demonstrating that community-driven approaches can deliver cost-effective and socially accepted resilience outcomes.[278]

Strengthen territorial resilience through place-based development strategies

Place-based development strategies are essential for translating European climate and resilience objectives into locally effective action. Climate risks and economic structures vary significantly across regions; resilience policies must therefore be tailored to territorial contexts rather than applied uniformly. The EU's Transformative Innovation for Climate Resilience program, implemented through EIT Climate-KIC, exemplifies this approach by supporting co-creation processes in cities and regions that combine governance reform, technological innovation, and social experimentation.[279]

Similarly, the Pathways2Resilience *initiative* has selected 40 regions and communities to co-design long-term adaptation strategies, supported by cascade funding for local climate planning in areas exposed to drought, floods, wildfires, and heat.[280] These initiatives illustrate how EU-level coordination can empower local actors rather than substitute for them.

Multi-level governance is increasingly recognized as a prerequisite for effective resilience. In June 2025, the European Committee of the Regions and the European Commission signed a joint action plan to strengthen water resilience, formally embedding local and regional authorities in EU climate governance. The Committee of the Regions has also called for a regional vulnerability scoreboard and a "72-hour crisis response strategy" tailored to territorial conditions, reflecting lessons from recent climate and energy shocks.[281]

Finally, rural and remote areas require particular attention. Energy communities have emerged as a powerful lever of resilience in these contexts, enabling small municipalities to generate, store, and share renewable energy locally. The EU Rural Vision initiative supports rural energy-community hubs that strengthen local autonomy, reduce emissions, and retain economic value within communities. Such place-based strategies enhance social cohesion, reduce territorial inequalities, and empower citizens as active agents of resilience rather than passive recipients of policy.

[276] REScoop.eu. (2022). *Annual report*
[277] OECD. (2021). *Building resilience through local development*
[278] European Commission. (2023). *EU climate action progress report 2023*
[279] EIT Climate-KIC. (2022). *Transformative innovation for climate resilience*
[280] European Commission. (2023c). *Pathways2Resilience: Selected regions and communities*
[281] Committee of the Regions. (2024). *Strengthening local and regional resilience to climate risks*

Conclusion

The recommendations set out above find strong external validation in Mario Draghi's 2024 report on the future of European competitiveness. The report identifies three interlocking imperatives for Europe: closing the innovation gap, aligning decarbonization with competitiveness, and reducing strategic dependencies on third countries for energy and critical materials. On all three counts, Draghi's diagnosis reinforces the logic of this report: resilience and decarbonization are not constraints on European growth — they are preconditions for it. Europe's dependence on fossil fuels and imported materials is identified as a root cause of its competitiveness deficit — meaning that the supply chain transformation, sectoral decarbonization, and strategic re-centering advocated throughout this report are not aspirational add-ons, but the core of a credible European industrial strategy.[282] [283]

A common objection to the scale of investment implied by the Resilient Green scenario is that it would burden European firms with costs their global competitors do not bear, eroding competitiveness in the short term. This concern deserves to be taken seriously — but the evidence points in the other direction on both counts. First, the transition pays for itself. The modelling presented in this report demonstrates a positive return on investment by 2050 for front-loaded green and resilient capital allocation, with compounding benefits as energy security dividends, reduced input volatility, and productivity gains from new industrial solutions accumulate over time. Many of the technologies and processes that decarbonization has forced European firms to develop — in hydrogen, circular materials, grid flexibility, and sustainable logistics — represent competitive advantages in their own right, opening export markets and licensing opportunities that would not have existed without the transition imperative. Second, and perhaps more decisively, those who choose not to invest will not be spared the cost — they will simply bear it differently, and more harshly. The war in Iran and the subsequent energy price spike are only the latest illustration of a now-familiar dynamic: economies and companies whose supply chains remain fossil-fuel dependent, geographically concentrated, and strategically exposed absorb external shocks at full force, with no buffers, no alternatives, and no sovereignty. The question is not whether disruption will come — it is whether European industry will face it from a position of resilience or fragility.

Not all actors will be in a position to engage with the full ambition of the Resilient Green pathway at once. Smaller firms may face financing constraints; certain sectors face longer investment cycles or regulatory uncertainty that complicates long-term planning; and some regions lack the industrial infrastructure to transition rapidly. For these actors, adaptation remains a meaningful and valuable first step. Adjusting procurement practices, diversifying supplier bases, stress-testing logistics networks against climate and geopolitical scenarios, or simply reducing exposure to single-source energy dependencies — each of these actions builds resilience incrementally, without requiring the full transformation to be completed upfront. The direction matters as much as the pace: an economy that is moving toward sustainability and resilience, even gradually, is fundamentally better positioned than one that is standing still.

Across all scenarios modelled in this paper, the cost of inaction is substantial: delayed mitigation, fragmented governance, and persistent fossil-fuel dependencies generate structural GDP losses, rising adaptation expenditures, and heightened exposure to climate and geopolitical shocks. Conversely, a coordinated and front-loaded transition — embodied in the

[282] Draghi, M. (2024). *The Future of European Competitiveness*. European Commission, Brussels
[283] Institut Veblen. (2025). *Quels outils pour une politique industrielle européenne durable ?*

Resilient Green scenario — does more than avert damage: it unlocks productivity gains, energy security dividends, and endogenous innovation effects that place Europe on a higher long-term growth path. Building this economy will require shared commitment across financial institutions, firms, governments, and citizens: financial actors must scale investment in both mitigation and adaptation; corporates must redesign value chains and accelerate Scope 3 decarbonization; public authorities must provide clear long-term signals and targeted support; and civic institutions must sustain transparency, accountability, and social cohesion throughout the transition.

Time is of the essence. Europe can either shape the next industrial era or absorb its disruptions unprepared. The choice to invest decisively in resilience is also a choice for competitiveness, technological leadership, and long-term relevance. In this light, adopting a Resilience Pact for a Green Europe is not only economically rational — it is a strategic imperative. By acting now, Europe can transform vulnerability into strength and ensure that the continent thrives in an era defined by systemic volatility. The alternative is to confront the shocks of the coming decades from a position of fragility rather than leadership. As Ernst F. Schumacher wrote, "an ounce of practice is generally worth more than a ton of theory" — a maxim European business and government leaders should bear in mind as they move to address the key challenges of our age.

Appendix

This appendix covers the following areas:

I. Model parameters and calculations

II. Additional sector deep dives

1. Beauty
2. Construction and Public Works
3. Defense

I. Model parameters and calculations

Model's core equation

The model aims at quantifying the macroeconomic impact of climate change and the transition to a low-carbon economy for Europe by 2050. It translates physical impacts and transition dividends into a single metric: the variation of total GDP relative to a "no-damage potential GDP" baseline.

The central equation used throughout the scenarios is:

$$\Delta \text{TotalGDP} = \text{Climate impact} + \text{D1} + \text{D2} + \text{D3} + \text{D4} + \text{D5} + \text{PathDep} + \text{Geopolitical impact}$$

Where each component expresses a percentage change of potential GDP due to a distinct economic mechanism.

Choice of timeframe

We selected 2050 as the model's time horizon because it serves as a clear policy and analytical benchmark. Mid-century aligns with the EU's net-zero target under the Green Deal and Climate Law, while also matching the standard range of robustness for long-term economic models (around 25–30 years) and allowing quantitative consistency with major sources such as the NGFS macroeconomic scenarios. By contrast, 2035 is too short-term to capture compounding physical and transition effects, and 2100, though useful for climate science, is macroeconomically too uncertain. Hence, 2050 stands as the common denominator linking all relevant projections within a rigorous and coherent timeframe, with the detailed motivations and underlying sources documented in the table below.

Source	Explicit time horizon
NGFS (2024/2025) Climate Scenarios – Phase IV–V	Simulates global and regional GDP, inflation, emissions, energy mix and damage to 2050, with some extensions to 2100 for temperature and physical damage. 2050 is their *economic* projection cutoff; 2100 is climatological.
Banque de France (2024)	Uses NGFS data and publishes impacts on European GDP to 2050; post-2050 numbers are typically scenario-storyline only.
ADEME (2023)	The *macro-économie et transition écologique* reports give quantified damage and sectoral losses for France and Europe to 2050, sometimes providing trend extensions beyond but using 2050 as the "reference" for policy evaluation.
Bilal & Känzig (2024)	Estimate a *temperature-GDP elasticity* without fixing an endpoint, but their empirical simulations are applied to 21st-century warming paths typically assessed at 2050 and 2100. Using 2050 allows direct integration with NGFS/ADEME trajectories.
Stern (2006)	Main illustrative paths end by 2050 for stabilization at 550 ppm CO_2e, then discuss century-scale extensions; again, 2050 is the economic-policy timescale.
European Commission (2024) – EU Energy Outlook	Projects the energy mix and GDP interaction to 2050 under all "Fit-for-55" and "Reference" scenarios.

Exhibit 20 – Source: Ardabelle Capital interviews and analysis.

Choice of baseline

Baseline EU27 nominal GDP for 2024 is set at €18 trillion. While recent Eurostat data place 2023 GDP at around €16-17 trillion and imply a 2024 level closer to €16.8 trillion, this slightly higher starting point remains consistent with international sources such as the IMF and does not materially affect our relative results. The baseline real growth rate in the absence of climate damage or additional policy costs is set at 1.1% per year, positioned at the midpoint of the range used by major forecasting and scenario providers for the European Union.

Source	Horizon	Long-term real GDP growth assumption	Notes
European Commission, Ageing Report 2024	2025–2070	0.9% – 1.1% (EU27 average potential growth)	Official macro-fiscal baseline for EU sustainability exercises.
IMF, World Economic Outlook (Oct. 2024)	2024–2029	≈ 1.3% (Euro area) → converging to 1.0% after 2030	Medium-term convergence to ~1% assumed as demographic drag intensifies.
OECD, Economic Outlook (2024)	2025–2060	1.0% – 1.2% for EU aggregate	Derived from potential output model.
NGFS, Phase V macro baseline (2024/2025)	2020–2050	≈ 1% – 1.2% for advanced economies	"Current policies" scenario baseline before climate shocks.
ADEME (2023)	France macro baseline	≈ 1% real p.a. (neutral macro path)	Serves as the benchmark before damage functions.
Banque de France (2024)	Stress-test reference	1% – 1.2%	Used as neutral scenario for solvency analysis.

Exhibit 21 – Source: Ardabelle Capital interviews and analysis.

Hence the baseline GDP 2050 (excluding climate damage and extra mitigation costs):

$$\mathbf{GDP}_{\mathbf{2050},\boldsymbol{baseline}} = \mathbf{18T} \times (\mathbf{1} + \mathbf{0.011})^{\mathbf{26}}$$

$$\mathbf{18} \times \mathbf{1.011}^{\mathbf{26}} \approx \mathbf{18.5} \times \mathbf{1.3290} \approx \mathbf{23.92T} \approx \mathbf{24T}$$

This is what we will refer to as the "2050-Potential GDP for Europe".

Effects of climate change on the economy

Bilal and Känzig (2024) provide one of the most robust econometric estimates of the causal macroeconomic impact of global temperature shocks on output, using high-frequency identification and panel VAR techniques across 174 countries. The implied elasticity (around −12% GDP per +1°C) lies at the upper end of plausible global climate damage functions in integrated macro–climate models and, when applied to a +3°C pathway, yields cumulative output losses on the order of −25 to −30% of global GDP by mid-century, in line with the "catastrophic" damage ranges reported in NGFS scenarios and the Stern Review. NGFS (Phase

IV/V) and ADEME scenarios complement this by providing harmonized climate–economic pathways and sectoral bottom-up assessments, typically indicating aggregate losses of roughly −10% to −15% of GDP by 2050 under weak or delayed transition trajectories, which are used here to calibrate European regional damage and to decompose impacts into physical risks (about two-thirds) versus resilience and energy-system fragilities (about one-third). Finally, Stern (2006) suggests that stabilization pathways require mitigation expenditures of roughly 1% of global GDP per year, which is used as a benchmark for central policy costs in the resilient green and fragile green scenarios, capturing the trade-off between near-term investment and long-run avoided damage.

European population and level of employment

The total number of EU employees in 2024 was 197.6 million people (Eurostat). Using Eurostat's projections (European population of 447.9 million people in 2050 with an employment rate of 78% in 2050 and a stable working-age population rate), we made those calculations to find the 2050 "Business as usual" number of employees in Europe:

	Total population (m)	Working-age population (m)	Number of employees (m)
2024	449	260	197.6
2050	447.9	259.3	202.3

Exhibit 22 – Source: Ardabelle Capital interviews and analysis.

So, we will consider a rounded 2050 number of European employees of 202 million people.

Summary of core hypotheses for Scenario quantification (EU27 Horizon 2050)

Dimension	Quantitative Assumption	Source / Justification
Time horizon	2024 → 2050 (26 years)	Chosen to align with NGFS & ADEME mid-century climate–economic scenarios
GDP baseline (nominal)	€18 trillion	IMF
Baseline growth (no damage, no policy cost)	+1.0% p.a. → 2050	EC Spring Forecast (2024), IMF (2024), consistent with slow-growth baseline
Employment baseline	198 million (2024)	Eurostat LFS (2024); OECD & IMF consistency check
GDP per worker (2024)	≈ €91,000 / worker	Derived from GDP ÷ employment
Temperature elasticity (global)	−10% world GDP per +1°C	Average between IMF and Bilal
High-warming scenario (Status Quo)	+2.7°C to +3.5°C by 2100	NGFS (2025); IPCC SSP2-6.0 equivalent

Exhibit 23 – Source: Ardabelle Capital interviews and analysis.

The four Scenarios for Europe

Scenario	Resilience (adaptation)	Sustainability (mitigation)	Expected macro profile
Status quo	Low	Low	High damage, structural vulnerability
Fortress brown	High	Low	Security focus but high emissions → climate costs delayed
Fragile green	Low	High	Decarbonization without resilience → exposure to shocks
Resilient green leadership	High	High	Joint mitigation & adaptation → sustainable and robust growth

Exhibit 24 – Source: Ardabelle Capital interviews and analysis.

Impact of Climate Change

Potential EU27 GDP in 2050 (without climate impacts) is set at €24 trillion. With a baseline warming of ΔT = 2.4 °C and a damage coefficient γ of 10 % GDP loss per additional °C, leading us to the following equation to replicate the climate impact on GDP:

$$Climate\ impact = -\gamma * \Delta T$$

Impact of Geopolitical Shocks

We consider all the potential geopolitical disruptions which could impact the EU GDP through the energy / raw materials canal. For quantification, we considered the analysis developed by Bruegel (*The Economic Policy Consequences of the War*), assuming that a disruption comparable to the War in Ukraine is at the origin of a 1.4% malus for the GDP. Counting historical episodes of major energy and commodity supply shocks and using academic measures of geopolitical risk (Caldara & Iacoviello's GPR[284]), an arrival rate of ≈ 0.11–0.15 events/year (≈3–4 events between 2023 and 2050, i.e. one every ~7–9 years) is historically plausible. We therefore use 3.5 equivalent disruptions to 2050 as our baseline.

Parameters and economic logic

Each term (D1–D5, PathDep) represents a "dividend" or "cost" of transition policies, added to or subtracted from the baseline climate impact.

Parameter	Description	Economic Transmission Channel	Sign
D1 – Avoided Damage	Reduction of physical climate losses due to lower warming (ΔT ↓).	Lower exposure to droughts, floods, productivity losses.	Positive
D2 – Productivity & Innovation	Efficiency and technology gains from green investment.	Learning-by-doing, diffusion of renewable technologies, higher TFP.	Positive

[284] Caldara, D., & Iacoviello, M. (2022). *Measuring geopolitical risk.* American Economic Review, 112(4), 1194–1225.

D3 – Social Co-benefits	Health, well-being, and social cohesion effects.	Less air pollution → lower mortality, higher labor participation.	Positive
D4 – Diversification / Resilience	Lower dependence on fossil imports, improved trade balance.	Energy security, reduced price shocks, improved Terms of Trade.	Positive
D5 – Natural Capital	Restoration of ecosystems improving long-term productivity.	Better soil, water, biodiversity, tourism potential.	Positive
PathDep – Path-dependency	Lock-in costs from fossil infrastructures and delayed transition.	Stranded assets, reconversion costs, productivity losses.	Negative

Exhibit 25 – Source: Ardabelle Capital interviews and analysis.

The following table summarizes the economic reasoning and our working hypotheses behind each component of the macroeconomic model. It details how each effect (Climate Impact, D1–D5, Path-dependency & Geopolitical Impact) operates through specific transmission channels, with indicative magnitude and time horizon by 2050.

No.	Effect	Economic Mechanism	Transmission Channel	Relative Weight – 2050
Climate impact (gross)	Increase in temperature → physical losses on capital, labor, agricultural output, health, and infrastructure	ΔT ↑ → more disasters, thermal stress, lower yields	**Strong** (−10% to −15%) in unmanaged scenarios	Increasing (full effect around 2050–2070)
D1 – Avoided Damage	Reduction in ΔT → mitigation of physical losses	Fewer droughts, floods, agricultural losses, climate-related diseases	**Strong** (+4% to +6%) in scenarios with ΔT < 2°C	Medium term (2040–2050)
D2 – Productivity (innovation, efficiency)	Structural transformation of the economy → higher productivity of capital and labor	Green investments → technological diffusion → increasing returns	**Medium to strong** (+2% to +5%) depending on green scenario	Medium term (2035–2050)
D3 – Social Co-benefits	Reduced pollution → lower mortality, better health, social well-being, urban attractiveness	Transition → cleaner air → lower health costs, higher labor participation	**Low to medium** (+0.3% to +1.0%)	Rapid (visible from 2030)
D4 – Diversification / Resilience (incl. Terms of Trade)	Lower dependence on fossil imports → macro stability and trade balance gains	Less exposure to price shocks → greater competitiveness + Terms of Trade gains	**Medium** (+1% to +2.5%)	Gradual (2030–2050)
D5 – Natural Capital	Ecosystem restoration → ecological services → stabilization of agricultural, water, and tourism productivity	Rehabilitation of soils, forests, biodiversity → mitigates climate shocks	**Low to medium** (+0.3% to +0.8%)	Slow (long-term effect)
Path-dependency	Lock-in in a fossil-based model → future	Fossil infrastructure → stranded assets,	**Negative** (−1,5) in “brown” scenario	Long-term (post-2040)

	adaptation and obsolescence costs	conversion costs → lower productivity		
Geopolitical Impact	Value chain disruptions → adaptation costs	Lower access to resources → cost increase → inflation	**Negative** (-0,15%) in "brown" scenarios	Omnipresent

Exhibit 26 – Source: Ardabelle Capital interviews and analysis.

Scenarios hypothesis:

Scenario	D1 - Damage avoided	D2 - Productivity & jobs dividend	D3 - Social & co-benefit	D4 - Diversification (+ToT)	D5 - Natural Capital	PathDep	Geopolitical Impact
Status Quo	0%	0%	0%	0%	0%	0%	3.85%
Fortress Brown	0%	1.5%	0.3%	3%	0.20%	-1.50%	3.85%
Fragile Green	12%	5%	1%	2%	2%	0%	0%
Resilient Green	12%	9%	4%	5%	3%	0%	0%

Exhibit 27 – Source: Ardabelle Capital interviews and analysis.

Baseline	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
GDP	18,2	18,4	18,6	18,8	19,0	19,2	19,4	19,6	19,9	20,1	20,3	20,5	20,8	21,0	21,2	21,4	21,7	21,9	22,2	22,4	22,6	22,9	23,1	23,4	23,7	**23,92**

STATUS QUO	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
"Natural" GDP Growth	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Potential GDP	18,2	18,4	18,5	18,7	18,9	19,1	19,3	19,5	19,7	19,9	20,1	20,3	20,5	20,7	20,9	21,1	21,3	21,5	21,7	22,0	22,2	22,4	22,6	22,9	23,1	23,3
ΔT (°C)	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04
Cumulated Δ T	0,04	0,07	0,11	0,14	0,18	0,21	0,25	0,29	0,32	0,36	0,39	0,43	0,47	0,50	0,54	0,57	0,61	0,64	0,68	0,72	0,75	0,79	0,82	0,86	0,89	0,93
Impact_climat brut	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%
D_1 Avoided Damage	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
D_2 Productivity	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
D_3 Social Co-Benefits	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
D_4 Diversification (+ToT)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
D_5 Natural Capital	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PathDep	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Total Net Impact	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%
GDP UE - Climate effects	17,9	18,0	18,1	18,1	18,2	18,3	18,4	18,5	18,5	18,6	18,7	18,8	18,8	18,9	19,0	19,1	19,2	19,2	19,3	19,4	19,5	19,6	19,6	19,7	19,8	19,9
Geopolitical Shocks	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%
Total Effect	0,42%	0,42%	0,42%	0,42%	0,42%	0,42%	0,42%	0,42%	0,42%	0,42%	0,42%	0,42%	0,42%	0,42%	0,42%	0,42%	0,42%	0,42%	0,42%	0,42%	0,42%	0,42%	0,42%	0,42%	0,42%	0,42%
GDP UE 2050 (T€)	18,08	18,15	18,23	18,30	18,38	18,45	18,53	18,61	18,69	18,76	18,84	18,92	19,00	19,08	19,16	19,24	19,32	19,40	19,48	19,56	19,64	19,72	19,81	19,89	19,97	**20,06**

FRAGILE GREEN	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
"Natural" GDP Growth	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Potantial GDP	18,2	18,4	18,5	18,7	18,9	19,1	19,3	19,5	19,7	19,9	20,1	20,3	20,5	20,7	20,9	21,1	21,3	21,5	21,7	22,0	22,2	22,4	22,6	22,9	23,1	23,3
ΔT (°C)	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Cumulated Δ T	0,01	0,01	0,02	0,02	0,03	0,03	0,04	0,04	0,05	0,05	0,06	0,06	0,07	0,07	0,08	0,08	0,09	0,09	0,10	0,10	0,11	0,11	0,12	0,12	0,13	0,13
Impact_climat brut	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%
D_1 Avoided Damage	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%
D_2 Productivity	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%
D_3 Social Co-Benefits	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%
D_4 Diversification (+ToT)	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%
D_5 Natural Capital	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%
PathDep	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Total Net Impact	0,50%	0,50%	0,50%	0,50%	0,50%	0,50%	0,50%	0,50%	0,50%	0,50%	0,50%	0,50%	0,50%	0,50%	0,50%	0,50%	0,50%	0,50%	0,50%	0,50%	0,50%	0,50%	0,50%	0,50%	0,50%	0,50%
GDP - Climate Effects	18,1	18,3	18,6	18,8	19,1	19,3	19,6	19,9	20,1	20,4	20,7	21,0	21,2	21,5	21,8	22,1	22,4	22,7	23,0	23,3	23,6	24,0	24,3	24,6	24,9	25,3
Geopolitical Shocks	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%	-0,15%
Total Effect	1,35%	1,35%	1,35%	1,35%	1,35%	1,35%	1,35%	1,35%	1,35%	1,35%	1,35%	1,35%	1,35%	1,35%	1,35%	1,35%	1,35%	1,35%	1,35%	1,35%	1,35%	1,35%	1,35%	1,35%	1,35%	1,35%
GDP UE 2050 (T€)	18,24	18,49	18,74	18,99	19,24	19,50	19,77	20,03	20,30	20,57	20,85	21,13	21,42	21,71	22,00	22,29	22,59	22,90	23,21	23,52	23,83	24,16	24,48	24,81	25,14	**25,48**

FORTRESS BROWN	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
"Natural" GDP Growth	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Potential GDP	18,18	18,36	18,55	18,73	18,92	19,11	19,30	19,49	19,69	19,88	20,08	20,28	20,49	20,69	20,90	21,11	21,32	21,53	21,75	21,96	22,18	22,40	22,63	22,86	23,08	23,31
ΔT (°C)	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04
Cumulated Δ T	0,04	0,07	0,11	0,14	0,18	0,21	0,25	0,29	0,32	0,36	0,39	0,43	0,47	0,50	0,54	0,57	0,61	0,64	0,68	0,72	0,75	0,79	0,82	0,86	0,89	0,93
Impact_climat brut	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%	-0,43%
D_1 Avoided Damage	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
D_2 Productivity	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
D_3 Social Co-Benefits	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
D_4 Diversification (+ToT)	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
D_5 Natural Capital	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%
PathDep	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%
Total Net Impact	-0,48%	-0,48%	-0,48%	-0,48%	-0,48%	-0,48%	-0,48%	-0,48%	-0,48%	-0,48%	-0,48%	-0,48%	-0,48%	-0,48%	-0,48%	-0,48%	-0,48%	-0,48%	-0,48%	-0,48%	-0,48%	-0,48%	-0,48%	-0,48%	-0,48%	-0,48%
GDP UE - Climate Effect	17,91	17,83	17,74	17,66	17,57	17,49	17,40	17,32	17,24	17,15	17,07	16,99	16,91	16,82	16,74	16,66	16,58	16,50	16,42	16,34	16,27	16,19	16,11	16,03	15,96	15,88
Geopolitical Shocks	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Total Effect	0,52%	0,52%	0,52%	0,52%	0,52%	0,52%	0,52%	0,52%	0,52%	0,52%	0,52%	0,52%	0,52%	0,52%	0,52%	0,52%	0,52%	0,52%	0,52%	0,52%	0,52%	0,52%	0,52%	0,52%	0,52%	0,52%
GDP UE 2050 (T€)	18,09	18,19	18,28	18,38	18,47	18,57	18,66	18,76	18,86	18,96	19,05	19,15	19,25	19,35	19,45	19,55	19,66	19,76	19,86	19,96	20,07	20,17	20,27	20,38	20,49	**20,59**

Results:

Resilient Green	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
"Natural" GDP Growth	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Potential GDP	18,18	18,36	18,55	18,73	18,92	19,11	19,30	19,49	19,69	19,88	20,08	20,28	20,49	20,69	20,90	21,11	21,32	21,53	21,75	21,96	22,18	22,40	22,63	22,86	23,08	23,31
ΔT (°C)	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Cumulated Δ T	0,01	0,01	0,02	0,02	0,03	0,03	0,04	0,04	0,05	0,05	0,06	0,06	0,07	0,07	0,08	0,08	0,09	0,09	0,10	0,10	0,11	0,11	0,12	0,12	0,13	0,13
Impact_climat brut	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%	-0,06%
D_1 Avoided Damage	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%	3,08%
D_2 Productivity	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%
D_3 Social Co-Benefits	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%	0,16%
D_4 Diversification (+ToT)	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%	0,20%
D_5 Natural Capital	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%	0,12%
PathDep	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Total Net Impact	0,62%	0,62%	0,62%	0,62%	0,62%	0,62%	0,62%	0,62%	0,62%	0,62%	0,62%	0,62%	0,62%	0,62%	0,62%	0,62%	0,62%	0,62%	0,62%	0,62%	0,62%	0,62%	0,62%	0,62%	0,62%	0,62%
GDP UE - Climate effect	18,11	18,22	18,34	18,45	18,56	18,68	18,80	18,91	19,03	19,15	19,27	19,39	19,51	19,63	19,75	19,87	19,99	20,12	20,24	20,37	20,49	20,62	20,75	20,88	21,01	21,14
Geopolitical Shocks	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Total Variation	1,62%	1,62%	1,62%	1,62%	1,62%	1,62%	1,62%	1,62%	1,62%	1,62%	1,62%	1,62%	1,62%	1,62%	1,62%	1,62%	1,62%	1,62%	1,62%	1,62%	1,62%	1,62%	1,62%	1,62%	1,62%	1,62%
GDP UE 2050 (T€)	18,29	18,59	18,89	19,20	19,51	19,82	20,14	20,47	20,80	21,14	21,48	21,83	22,18	22,54	22,91	23,28	23,65	24,04	24,43	24,82	25,23	25,63	26,05	26,47	26,90	**27,34**

Exhibit 28 – Source: Ardabelle Capital interviews and analysis.

Scenario	BASELINE	STATUS QUO	FORTRESS BROWN	FRAGILE GREEN	RESILIENT GREEN
EU GDP 2035 (€T)	21.2	18.8	19.1	20.9	21.5
Δ T° 2035		0.39	0.39	0.06	0.06
GDP 2050 (€T)	23.9	20,1	20.6	25.5	27.3
Δ T° 2050		0.93	0.93	0.13	0.13
Δ vs Baseline GDP	*0%*	*-16%*	*-14%*	*6%*	*14%*

Exhibit 29 – Source: Ardabelle Capital interviews and analysis.

GDP creation across the four scenarios

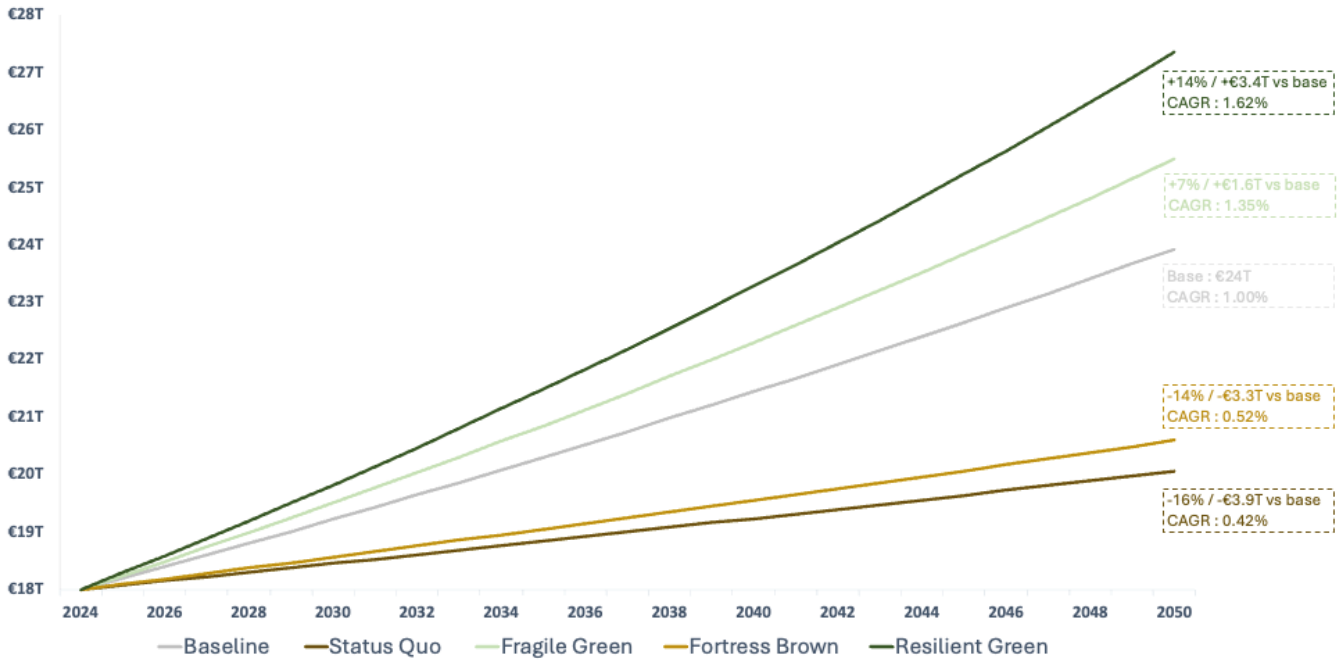

Exhibit 30 – Source: Ardabelle Capital interviews and analysis.

Detail of the recommended split between investment in mitigation and adaptation efforts

Status Quo (ΔT ≈ 2.4°C (IPCC SSP5-8.5 scenario), no resilience): Policy inaction leads to minimal mitigation and reactive adaptation, with total expenditure rising as climate damage accumulate. Adaptation dominates later decades, reflecting reactive hardening, emergency relief, and local infrastructure investment.

Window	Mitigation (% GDP)	Adaptation (% GDP)	Total (% GDP)
2025–2030	0.2%	0.3%	0.5%
2030–2040	0.3%	0.5%	0.8%
2040–2050	0.3%	0.8%	1.1%

Exhibit 31 – Source: Ardabelle Capital interviews and analysis.

Fragile Green (ΔT ≈ 1.6°C (IPCC SSP1-1.9 scenario), uneven, fragmented transition): Significant green investment begins, dominated by mitigation, but governance fragmentation limits efficiency, innovation diffusion, and social/industrial dividends.

Window	Mitigation (% GDP)	Adaptation (% GDP)	Total (% GDP)
2025–2030	1.5%	0.4%	1.9%
2030–2040	1.0%	0.5%	1.5%
2040–2050	0.8%	0.6%	1.4%

Exhibit 32 – Source: Ardabelle Capital interviews and analysis.

Fortress Brown (ΔT ≈ 2.4°C (IPCC SSP5-8.5 scenario), protectionist, fossil-based resilience): High spending secures domestic energy supply and hard infrastructure but contributes little to decarbonization. Adaptation and resilience dominate, and mitigation largely reinforces fossil infrastructure.

Window	Mitigation (% GDP)	Adaptation (% GDP)	Total (% GDP)
2025–2030	0.7%	1.0%	1.7%
2030–2040	0.8%	1.0%	1.8%
2040–2050	0.8%	1.0%	1.8%

Exhibit 33 – Source: Ardabelle Capital interviews and analysis.

Resilient Green (ΔT ≈ 1.6°C (IPCC SSP1-1.9 scenario), coordinated, transformative): Strong, coordinated mitigation front-loads spending in the 2020s, generating large, avoided damage and productivity dividends. Adaptation is strategic, focused on nature-based solutions and targeted hardening.

Window	Mitigation (% GDP)	Adaptation (% GDP)	Total (% GDP)
2025–2030	1.5%	0.7%	2.2%
2030–2040	1.0%	0.7%	1.7%
2040–2050	0.8%	0.7%	1.5%

Exhibit 34 – Source: Ardabelle Capital interviews and analysis.

II. Additional sector deep dives

Beauty

Overview of risks and materiality

The cosmetics and beauty industry encompasses a complex global ecosystem spanning ingredient producers, chemical formulators, manufacturers, packagers, distributors, and retailers. This diversity exposes the sector to a broad spectrum of risks: product safety, regulatory compliance, environmental performance, ethical sourcing, litigation, and reputational integrity. While beauty brands are consumer-facing, most of their environmental and operational vulnerabilities originate upstream in the supply chain.

Regulatory pressures are intensifying. Approximately 2,000 hazardous chemicals were banned in the EU between 2010 and 2022, directly affecting cosmetic formulations and product categories.[285] These evolving frameworks heighten compliance costs and accelerate the need for reformulation. At the same time, consumer expectations of transparency–particularly regarding natural ingredients and sustainable palm oil–have redefined brand credibility as a function of traceability.[286]

In parallel, climate-induced volatility is reshaping the availability and cost of agricultural and natural inputs. Droughts, floods, and pest shifts are translating into raw material inflation and supply uncertainty. As Rähse[287] observes, while marketing expenditures dominate industry costs, a sustained increase in manufacturing expenses could materially affect competitiveness, demonstrating that sustainability and resilience are increasingly inseparable.

Emissions and materiality: The dominance of Scope 3

Cosmetics companies exhibit a highly unbalanced emissions structure, with Scope 3 emissions representing often more than 90% of total emissions (Exhibit 35). These stem primarily from upstream activities such as ingredient cultivation, chemical processing, and packaging material production, as well as downstream activities including product distribution and end-of-life disposal.

[285] European Environmental Bureau. (2023). *Chemicals banned in the EU between 2010 and 2022: Implications for the cosmetics sector*
[286] Deloitte. (2023). *Sustainability and transparency in the beauty industry: How consumer expectations are reshaping the market*.
[287] Rähse, W. (2022). *Cosmetic creams: Development, manufacture and marketing of effective skin care products* (2nd ed.). Wiley-VCH.

Structure of total emissions for 9 major actors of the Beauty Industry

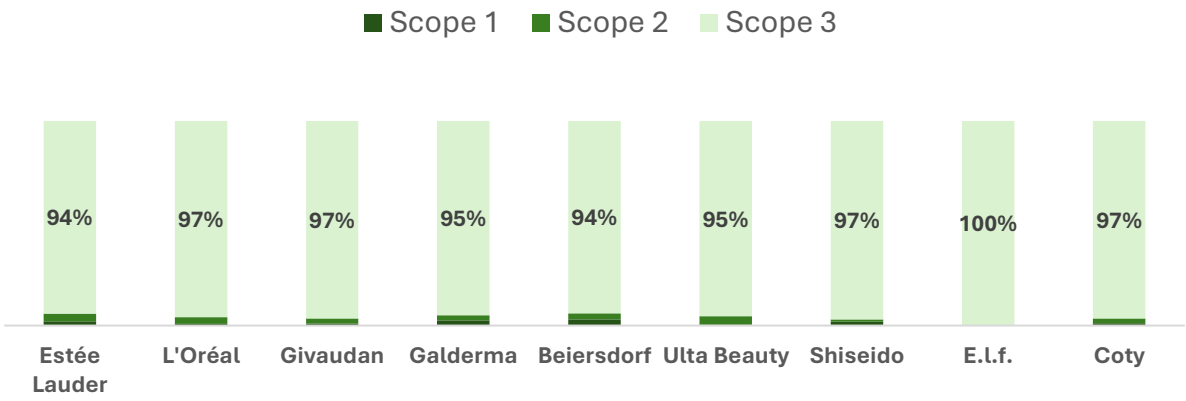

Exhibit *35* – Source: Ardabelle Capital analysis, based on the 2024 Sustainability or Integrated Reports of all 9 companies[288]

While companies have made visible progress in decarbonizing Scope 1 and 2 emissions through renewable energy sourcing and operational efficiency, inconsistent disclosure of Scope 3 categories continues to limit investors' ability to assess exposure. Schulman et al.[289] emphasize that supplier engagement is the primary lever for decarbonization in consumer goods sectors where upstream processes dominate emissions.

Structure of Scope 3 emissions for 9 major actors of the Beauty Industry

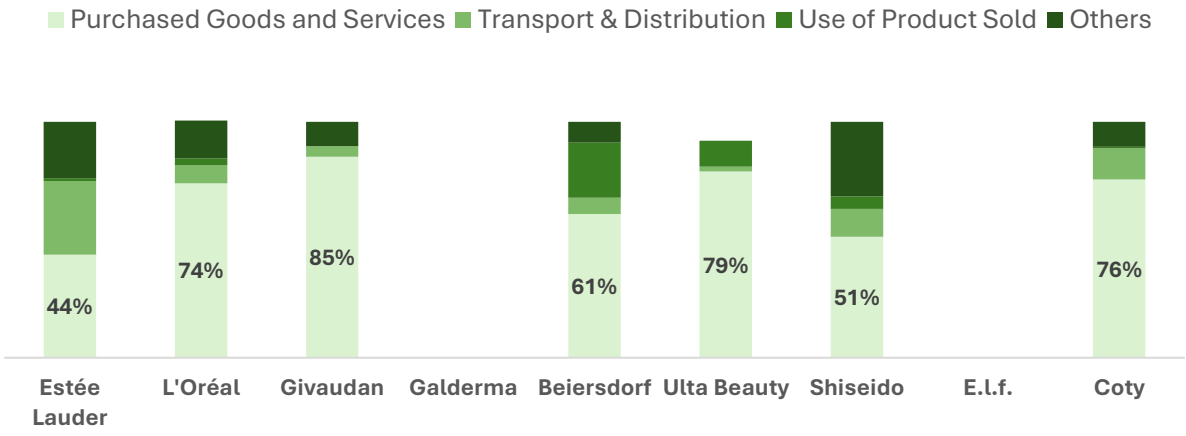

Exhibit 36 – Source: Ardabelle Capital Analysis based on the 2024 Sustainability or Integrated Reports of all 9 companies.[290]

The breakdown of Scope 3 emissions presented in Exhibit 36 enables a more granular understanding of where decarbonization efforts should be prioritized across the cosmetics and beauty value chain. By mapping emissions to specific supply chain stages, this analysis reveals that the most significant reduction opportunities lie upstream–particularly in the sourcing of ingredients and the production of packaging materials. These stages not only dominate the

[288] 99.7% for E.l.f. but 100% due to rounding

[289] Schulman, A., Peters, D., & Vang, J. (2021). *Scope 3 emissions and supplier engagement in the consumer goods sector*. Journal of Sustainable Business Strategy, 8(2), 45–63.

[290] No data available for either Galderma or E.l.f

sector's carbon footprint but also concentrate the highest exposure to environmental and regulatory risks, from deforestation-linked commodities to fossil-based plastics. In contrast, downstream categories such as distribution and product use, while not negligible, account for a smaller share of total emissions. This decomposition provides a strategic basis for targeting interventions where they will have the greatest impact–namely, supplier engagement, materials innovation, and circular design.

Packaging: Circularity and impact shifting

Packaging represents the most visible and consistently reported sustainability challenge across cosmetics companies. Its environmental footprint begins at the extraction stage: most plastic packaging derives from fossil fuels, and plastics were responsible for approximately 1.7 $GtCO_2eq$ in 2019, of which 84% arose during production and conversion.[291] Meanwhile, the European Union's Extended Producer Responsibility (EPR)[292] regulations, particularly the Packaging and Packaging Waste Regulation (PPWR), are intensifying accountability for packaging sustainability. These regulations mandate that producers finance the entire lifecycle of their packaging, including collection, sorting, and recycling. Non-compliance can lead to significant penalties, including fines and market restrictions, as determined by individual EU member states.

However, packaging substitution entails systemic trade-offs. Aluminum and glass alternatives are roughly 1.6 times more expensive and 2.5 to 4.3 times more carbon-intensive than plastics due to energy-intensive production.[293] Without a life-cycle perspective, material switching risks impact shifting–reducing plastic waste at the cost of higher embedded emissions. Nonetheless, reducing packaging weight and volume can generate operational efficiencies by lowering shipping and material costs. The challenge, therefore, lies not in replacing one material with another but in redesigning systems for reuse, recycling, and circularity.[294]

Formulation risks: Raw materials, water, and deforestation

Raw material dependency creates both physical and reputational risks. Although often overshadowed by packaging discussions, ingredients account for a substantial share of Scope 3 emissions, ranging from 18% to 82% in disclosed company data (Exhibit 36). The shift toward natural and "clean" beauty products has intensified reliance on biological inputs, many of which are vulnerable to climate stress and overexploitation. Water is the ubiquitous ingredient in cosmetics, comprising 60% to 95% of product formulas across creams, lotions, shampoos, and gels. Water stress threatens both manufacturing continuity and product composition. Companies such as Beiersdorf monitor water-related risks through tools like the WWF Water Risk Filter and WRI Aqueduct Atlas, assessing both physical scarcity and reputational implications of operations in water-stressed basins.[295]

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[291] Organization for Economic Co-operation and Development (OECD). (2023). *Global plastics outlook: Policy scenarios to 2060*.
[292] European Commission. (2023). *Proposal for a regulation on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/62/EC*.
[293] European Commission. (2024). *Impact assessment report: Accompanying the document proposal for a regulation on packaging and packaging waste*.
[294] Carbon Trust. (2023). *Impact report 2023*
[295] Beiersdorf AG. (2024). *Water*. In *Annual report 2024*.

Palm oil epitomizes the systemic vulnerability of cosmetic supply chains. Present in roughly 70% of beauty products,[296] it has been linked to 15% of deforestation in Indonesia (1990–2015) and 40% in Malaysia[297], with production concentrated in a few islands that face persistent labor and governance concerns. Substituting palm oil is complex: it is among the most productive oil crops per hectare, and alternatives often entail greater land use and energy demand. Addressing this challenge requires innovation in bio-based chemistry and life-cycle product design to avoid transferring impacts elsewhere in the system.[298] Thus, managing raw material dependency in cosmetics requires a holistic approach that balances environmental, social, and operational risks, emphasizing resilient sourcing, sustainable ingredient innovation, and comprehensive life-cycle strategies to mitigate both physical and reputational impacts.

Logistics and supply chain resilience

The cosmetics supply chain is deeply globalized and geographically fragmented. Approximately 90% of global palm oil production occurs in Malaysia and Indonesia, while manufacturing facilities are distributed across continents.

L'Oréal, for instance, operates 37 plants worldwide, only three of which are in the North Asia region, while sales are spread almost evenly between North America (27%), North Asia (23%), and Europe (34%).[299] This global configuration generates logistical complexity and vulnerability to geopolitical tensions, climate disruptions, and transport bottlenecks. Although Transport & Distribution typically represent around 6% of Scope 3 emissions (Exhibit 36), they remain a significant continuity risk, frequently identified in corporate filings. The sector's reliance on international freight and just-in-time delivery systems underscores the importance of regionalized production networks, supplier diversification, and low-emission logistics solutions.[300]

Operational levers and industry practices

The beauty sector is moving from incremental sustainability initiatives to systemic transformation. As climate pressures, material shortages, and evolving regulations reshape the landscape, companies are recognizing that long-term resilience depends on embedding sustainability across entire value chains–from raw materials and formulation to packaging and logistics. Like energy, agri-food, and manufacturing, the sector faces shared challenges: securing supply, reducing exposure to volatility, and achieving deep decarbonization. Yet, because most Scope 3 emissions reside with a dispersed ecosystem of SMEs, progress depends on aligning brand-level ambition with the operational realities of these suppliers.

Financing sustainable transitions

Decarbonizing Scope 3 emissions in the beauty sector requires direct financial support to enable supplier transformation. The sector's sustainability goals will only be met if SMEs have access to affordable capital to retool production, reformulate inputs, and transition to low-carbon packaging and logistics. LVMH's LIFE 360 Business Partners program provides co-

[296] Deloitte. (2024, December 2). *Start to scale: Cleaning up cosmetics*.
[297] Curtis, P. G., Slay, C. M., Harris, N. L., & Tyukavina, A. (2018). Classifying drivers of global forest loss. *Science, 361*(6407), 1108–1111.
[298] Carbon Trust. (2023). *Sustainable personal care ingredients: Riding the wave of innovation*.
[299] L'Oréal. (2024). *Universal Registration Document 2025*
[300] Flammini, A., Matuszak-Flejszman, A., & Verlinden, A. (2024). Transport-related emissions and transition strategies for sustainable supply chains. *Sustainability, 16*(17), 7749.

investment and technical assistance to suppliers by reducing their carbon footprint and adopting certified materials. The purpose of this initiative is to work closely with its supplier ecosystem – especially SMEs – to reduce emissions associated with raw materials and transportation, as these two categories are among the largest contributors to its Scope 3 impacts. LVMH set ambitious targets under LIFE 360: by 2030, it aims to reduce its Scope 3 emissions by 55% in intensity relative to its 2019 baseline.[301]

L'Oréal has gone further by launching sustainability-linked financing mechanisms, offering preferential rates to suppliers that meet SBTi-aligned emissions targets. Under its *L'Oréal for the Future* program, the Group's decarbonization trajectory was validated by the Science Based Targets initiative in 2024. One notable lever is the Solstice Fund, a debt fund jointly created with Chenavari Investment Managers, to help industrial suppliers – including SMEs within L'Oréal's value chain – finance significant decarbonization projects. L'Oréal committed an initial €50 million to Solstice in 2024 [302] to enable supplier access to financing for decarbonization of industrial processes, clean energy deployment, and clean transportation. The fund is also open to contributions from institutional and corporate investors beyond L'Oréal. In addition, L'Oréal has aligned its broader financing instruments with its sustainability goals: for instance, a €3 billion bond issued in 2022, one tranche (≈ €1.25 billion) of which is sustainability-linked.[303]

These initiatives demonstrate that financing sustainable transitions is not only about funding innovation but also about de-risking supply chains and ensuring that SMEs can deliver on shared climate commitments.

Data, measurement, and compliance

Robust data and harmonized measurement systems are the backbone of credible sustainability transformation. Companies across the beauty sector are adopting shared methodologies to assess and compare environmental performance, ensuring that supplier-level improvements translate into verifiable impact. The SPICE[304] framework (Sustainable Packaging Initiative for Cosmetics) co-founded by L'Oréal and Quantis in 2018 has become a cornerstone, enabling consistent life cycle assessments (LCAs) and eco-design benchmarks across diverse supplier networks. SPICE now includes around 25 core member companies (brands, packaging suppliers, NGOs) and several associated members. The initiative's flagship deliverable is the SPICE Tool, launched in 2020, which allows packaging designers to compute the environmental footprint of any cosmetics pack through its full life cycle–from raw material extraction, production, finishing/decoration, to end of life. The tool covers 16 environmental impact categories, including climate change, resource depletion, water use, effects on biodiversity, etc.

Shiseido's participation[305] in the TRASCE[306] (Traceability Alliance for Sustainable CosmEtics) consortium also reflects this push for transparency, as 18 leading firms collaborate on a shared digital platform to trace materials and components throughout the value chain. Through these

[301] LVMH. (2023, December). LIFE 360 Business Partners.
[302] L'Oréal. (2024). L'Oréal creates fund to help suppliers with sustainability transition.
[303] L'Oréal. (2022). L'Oréal successfully prices its inaugural €3 billion bond including a sustainability-linked tranche. *L'Oréal Finance*.
[304] Quantis. (2020). *SPICE launches publicly available ecodesign tool to measure and reduce the environmental footprint of cosmetics packaging*. CSRWire.
[305] Shiseido Company. (2023). Industry-wide efforts to ensure traceability: Shiseido joins TRASCE consortium. In *Shiseido Sustainability / Supplier compliance*.
[306] TRASCE Consortium. (2023). *Launching TRASCE: A shared commitment to improve traceability and sustainability to transform beauty supply chains*. TRASCE.

collective efforts, the sector is building a data foundation that strengthens compliance, supports science-based targets, and enhances consumer trust in sustainability claims.

Knowledge and capacity building

Financing and data systems alone are insufficient if suppliers lack the skills and technical know-how to implement sustainability measures. Capacity building has therefore become a central pillar of corporate sustainability strategies in beauty. LVMH's LIFE Academy[307] provides hands-on sustainability training for suppliers, focusing on eco-design, sustainable materials, and carbon accounting. LVMH training offer is both broad and discipline-specific, aiming to embed sustainable practices deep into the organization's operations and its wider supplier ecosystem. Rather than simply offering awareness sessions, the courses are structured around two complementary pillars: "Essentials", which provide a comprehensive overview of climate, biodiversity, and resource issues for all employees, and "Expert", which are tailored to specific business lines such as eco-design and packaging, responsible sourcing, chemical management, and sustainable store construction. The training is not only delivered online via e-learning modules, but there is also a dedicated campus – at the Association de la Vallée de la Millière near Paris – designed for immersive, in-person training, peer sharing, case-study work and action-planning with real projects. This kind of structured and practice-oriented capacity building is vital because many suppliers (particularly SMEs) lack internal sustainability expertise, and yet they are essential to reducing upstream emissions and embedding circular systems.

Estée Lauder[308], meanwhile, collaborates with NGOs to empower women-led enterprises in its supply base, providing training on sustainable sourcing, water stewardship, and biodiversity protection. For example, the company supports the program HERproject (run by the NGO Business for Social Responsibility / BSR) in its shea-butter supply chain. In fiscal 2021, after completing a two-year pilot with packaging suppliers, the company expanded the program into agriculture (targeting shea in West Africa) with the aim of strengthening cooperative capacity, providing training modules in financial planning, gender awareness, communication, problem solving and wellness for women producers. The model is designed to empower women in rural value chains and thereby enhance both livelihood resilience and supply-chain sustainability. These initiatives underscore that achieving Scope 3 decarbonization requires not only technological solutions but also shared knowledge and capacity that enable SMEs to participate meaningfully in the transition.

Green technology and innovation

Innovation is the engine of decarbonization in the beauty industry, driving changes in formulations, packaging, and logistics. LVMH's collaboration with Dow[309] is a strong example of how luxury brands are pushing material innovation to reduce their dependence on fossil virgin plastics. Under the LIFE 360 strategy, LVMH is working with Dow to integrate *bio-based* and *circular* plastics into perfume and cosmetics packaging, including premium components like caps and cream jars. The use of bio-based Surlyn (derived from waste cooking oils) and circular Surlyn (made from plastic waste feedstocks) promises to maintain design qualities–such as transparency and texture–while reducing carbon footprints. For instance, Guerlain's *La*

[307] LVMH. (2024). *2023 Social and Environmental Responsibility Report: Committed to positive impact*.
[308] The Estée Lauder Companies. (2023). *2023 Social Impact & Sustainability Report*.
[309] LVMH & Dow. (2023, January 25). *LVMH and Dow intend to collaborate to improve sustainable packaging across major perfume and cosmetics brands*.

Petite Robe Noire perfume line is among the first to include versions of its packaging using Surlyn's sustainable portfolio.

Similarly, L'Oréal's work with Carbios[310] illustrates how enzymatic recycling is becoming commercially viable. L'Oréal has committed to using PET plastics produced via Carbios' enzymatic process–a breakthrough that enables all types of PET waste (colored, multilayer, or opaque) to be depolymerized into its monomers, then repolymerized into recycled PET (r-PET) of virgin quality. In 2025, L'Oréal and Occitane en Provence signed multi-year contracts with Carbios to purchase biorecycled PET from its Longlaville plant, affirming strong demand for high-quality r-PET derived via enzymatic recycling. Earlier, in 2021, the first cosmetic bottle fully made from enzymatically recycled PET was developed by L'Oréal, marking a proof-of-concept for industrial rollout. These innovations show that circular packaging, enabled by enzyme-based technologies, is advancing from pilot to scaling.

Formulation innovation is becoming a decisive driver of decarbonization and resource efficiency across the beauty industry. By rethinking ingredient sourcing and chemistry, brands are significantly reducing both their carbon and ecological footprints. According to L'Oréal, biobased ingredients now account for 67% of the company's total raw material portfolio, with a target of reaching 75% by 2030.[311] To achieve these ambitious targets, L'Oréal actively engages its strategic suppliers through its L'Oréal for the Future (L4TF) program, supporting and ecnouraging them to set Science-Based Targets and develop their own Climate Transition Plans—demonstrating how large brands can systematically cascade decarbonization requirements across their supply base.[312]

Dsm-firmenich has positioned itself as a sustainability leader through its comprehensive application of Green Chemistry principles across its beauty ingredient portfolio. The company achieved a breakthrough by eliminating trifluoroacetic acid (TFA)–a persistent chemical commonly used in peptide synthesis–reaching a 100% TFA-free portfolio by early 2025.[313] Its flagship ingredient SYN-COLL CB, a natural-origin tripeptide for anti-aging, exemplifies this approach: manufactured using shorter synthesis routes, CMR-free solvents, and 100% renewable electricity in European facilities, resulting in a carbon footprint of just 5.2 kg CO_2 eq/kg.[314] The company was rewarded double A ratings from CDP for both Climate Change and Water Security.[315]

Another example comes from Givaudan[316], a Swiss company which has been a pioneer in production innovation, particularly through biotechnological approaches that significantly reduce environmental impact. For example, the company's acquisition of a Paris-based synthetic biology firm enables the production of hyaluronic acid with a tenfold reduction in CO_2 emissions, water use, electricity consumption, and waste compared to conventional methods. Bisabolol is now produced via fermentation from sugarcane, achieving 100% purity–compared with only 25% purity via petrochemical synthesis or highly resource-intensive extraction from Amazonian trees (ratio 1000:1). Givaudan also implements upcycling and sustainable sourcing practices. Cranberry seed oil is recovered from food industry waste in North America, while

[310] Carbios & L'Oréal. (2023, November 14). *Carbios and L'Oréal win Pioneer Award for the world's first enzymatically recycled cosmetic bottle*.
[311] L'Oréal. (2025). *Universal Registration Document*
[312] L'Oréal. (2023). *Climate Transition Plan*. L'Oréal Group.
[313] Personal Care Insights. (2025). *dsm-firmenich experts talk sustainability strategy to meet regulatory and consumer needs*
[314] dsm-firmenich. (2024). *Sustainability – Beauty & Care*.
[315] dsm-firmenich. (2025). *ESG Resources – Ratings, Benchmarks and Reports*
[316] Givaudan. (2024). *About Givaudan*.

patchouli and vetiver residues from perfume oil extraction are valorized rather than discarded. In India, women's cooperatives collect mango leaves during optimal periods, ensuring leaf harvesting does not compete with fruit production. Additionally, waste from algae-based bio stimulants is repurposed to create cosmetic ingredients.

Waste management and resource efficiency

In recent years, beauty companies have begun embedding circularity into their supply chains not only through packaging, but by valorizing waste streams and optimizing water use. The Body Shop[317] provides a strong example: through its *Community Fair Trade Recycled Plastic* program, the company sources plastic from informal waste collectors in India, cleans and sterilizes it, turns it into resin, and uses it in shampoo and conditioner bottles. This process not only redirects waste plastics into the manufacturing loop but also improves livelihoods in marginalized communities. Additionally, The Body Shop's *Community Fair Trade* initiative goes beyond plastic: it sources recycled paper gift bags made from cotton off-cuts and banana tree stems (waste materials) in Nepal, and handcrafted paper from Get Paper Industry, ensuring that materials which would otherwise be discarded are reintegrated into product packaging.

Governance and collaboration models

Achieving systemic change in the beauty sector depends on collaborative governance structures that promote shared accountability and industry-wide alignment. Initiatives such as TRASCE previously evocated illustrate how companies can jointly map and monitor supply chains to ensure traceability and compliance. The Ellen MacArthur Foundation's Global Commitment[318] also plays a role in aligning industry actors around shared targets. Since its launch in 2018 (in partnership with UNEP), it has mobilized over 1,000 organizations to endorse common goals around plastic packaging – including reusable design, elimination of problematic materials, and transparency via aligned metrics. The Global Commitment has helped raise the bar for what businesses are expected to disclose and deliver in terms of circular packaging. Another example is the EcoBeautyScore Consortium[319], which L'Oréal, LVMH, Henkel, Natura &Co and others launched in 2021 to create an industry-wide environmental impact scoring system. This framework intends to deliver a common method for assessing life cycle environmental impacts of beauty products (formula, packaging, usage), maintain a shared database of raw materials and standard ingredients, and produce a consumer-friendly scoring tool that allows product-to-product comparisons. By pooling expertise, setting common standards, and engaging policymakers, these governance models create the conditions for collective progress and scalable impact across the industry.

[317] The Body Shop. (n.d.). *Community Trade Recycled Plastic*.
[318] Ellen MacArthur Foundation. (n.d.). *Global Commitment Overview*
[319] "EcoBeautyScore Consortium is now live with 36 industry players." (2022, February 22). *Unilever Press Release*.

Operational levers and industry practices in the beauty sector

Category	Operational Lever / Practice	Description	Example(s)
1. Financing Sustainable Transitions	Supplier Co-Investment & Technical Support	Co-financing mechanisms and technical assistance	LVMH's *LIFE 360 Business Partners* program: 55% reduction in Scope 3 intensity by 2030 (vs. 2019).
	Sustainability-Linked Financing	Integrating sustainability criteria into lending and investment instruments	L'Oréal's *Solstice Fund* (€50M, launched 2024 with Chenavari Investment Managers)
2. Data, Measurement & Compliance	Life Cycle Assessment (LCA) & Eco-Design Frameworks	Harmonized measurement tools	SPICE (Sustainable Packaging Initiative for Cosmetics)
	Digital Traceability Platforms	Shared digital infrastructure	TRASCE unites 18 companies (including LVMH, L'Oréal, and Shiseido) using Transparency-One
3. Knowledge & Capacity Building	Supplier & Employee Sustainability Training	Structured programs to build technical expertise in eco-design, materials management, and carbon accounting across value chains.	LVMH LIFE Academy delivers "Essentials" and "Expert" modules
	Social Empowerment & Inclusive Supply Chains	Partnerships with NGOs	Estée Lauder collaboration with BSR's HERproject in shea supply chains, training women producers in financial literacy, gender equality, and sustainable sourcing practices in West Africa.
4. Green Technology & Innovation	Circular & Bio-Based Packaging Materials	Companies substituting fossil-based plastics with recycled or bio-based alternatives, maintaining luxury design quality.	LVMH x Dow partnership introduces bio-based and circular *Surlyn* for perfume packaging (e.g., *Guerlain's La Petite Robe Noire* line).
	Enzymatic & Advanced Recycling	Next-generation recycling technologies are closing material loops by regenerating plastics to virgin quality.	L'Oréal x Carbios collaboration enables enzymatic depolymerization of all PET types; multi-year supply contracts signed in 2025 for r-PET from the Longlaville plant.
	Biobased & Low-Impact Formulation	Ingredient innovation reduces reliance on petrochemicals and enhances biodegradability.	L'Oréal's 67% of raw materials now bio-based, target 75% by 2030; suppliers supported to set SBTs via L4TF program. dsm-firmenich SYN-COLL CB: 100% TFA-free portfolio by 2025; green chemistry synthesis with CMR-free solvents and renewable electricity; 5.2 kg CO_2 eq/kg footprint; CDP double A rating.

5. Waste Management & Resource Efficiency	Byproduct Valorization & Upcycling	Beauty brands integrating waste from other industries into formulations and packaging, reducing resource pressure.	L'Oréal using upcycled coffee grounds, and plant waste in skincare ingredients; The Body Shop sources recycling plastics from Indian waste collectors and banana stem paper from Nepal.
	Water Stewardship & Circular Manufacturing	Closed-loop and low-waste production systems	Estée Lauder and Unilever have installed closed-loop water systems at key facilities, optimizing reuse and reducing wastewater generation.
6. Governance & Collaboration Models	Industry-Wide Traceability & Standards	Cross-industry consortia aligning data and traceability methods	TRASCE Consortium develops a digital mapping platform for supplier traceability; EcoBeautyScore Consortium (L'Oréal, Unilever, LVMH, Henkel, Natura &Co).
	Collective Circularity Commitments	Voluntary frameworks aligning companies around global sustainability goals and transparent reporting standards	Ellen MacArthur Foundation's Global Commitment (with UNEP, 2018)

Exhibit 37 – Source: Ardabelle Capital interviews and analysis

Conclusion

The beauty sector's sustainability transformation depends on aligning financing, data, capacity, technology, and governance with the realities of a fragmented global supply base. By equipping SMEs with resources, tools, and knowledge, and embedding circular and low-carbon principles into every operational layer, brands are turning sustainability from a peripheral initiative into a core business system. When collective governance structures reinforce these efforts, Scope 3 reduction and resilience become achievable–not as aspirations, but as measurable outcomes.

Construction and Public Works

Overview of risks and materiality

The Construction and Public Works sector operates within structurally high exposure to economic, regulatory, environmental, and operational shocks. Due to its reliance on long project cycles, multi-tier subcontracting, and material-intensive processes, even minor disruptions can translate into cost overruns, safety incidents, or compliance failures. This structural sensitivity defines the materiality of risk across four dominant vectors.

Demand shocks arise from macroeconomic cycles, interest-rate conditions, and fluctuations in public investment. Residential construction in the European Union has contracted sharply since 2022 in response to higher mortgage rates, causing a reduction in housing permits and

new project starts.[320] Infrastructure demand remains dependent on fiscal positioning and political cycles: changes in public budgets can immediately affect the volume of road, rail, and energy projects.[321] Firms adapt through diversification toward renovation and maintenance markets, which exhibit lower cyclicality.

Supply shocks stem from price volatility and physical constraints in raw materials and logistics. The sector is highly dependent on cement, concrete, steel, aggregates, asphalt, and technical equipment, all of which experienced unprecedented inflation between 2021 and 2023 due to energy shocks and disrupted logistics.[322] Climate-related disruptions, such as flooding or heatwaves, increasingly affect quarry operations, transport routes, and on-site productivity.[323] The scarcity of skilled labor further intensifies supply fragility, with the sector reporting structural shortages across Europe and North America (International Labor Organization).[324]

Reputational and compliance shocks are driven by persistent risks in labor conditions, safety performance, and subcontracting opacity. Construction remains responsible for approximately 20% of workplace fatalities in OECD countries (ILO, 2023). Multiple investigations in Europe have highlighted illegal subcontracting, undeclared workers, and labor exploitation among temporary migrant labor forces in construction.[325] Environmental incidents–such as improper waste disposal or pollution–can cause significant reputational harm and project suspensions, particularly under EU procurement rules.

Regulatory shocks arise from accelerating decarbonization and circular-economy requirements. Embodied-carbon regulation is expanding through instruments such as France's RE2020[326], the EU Taxonomy, and the forthcoming Ecodesign for Sustainable Products Regulation.[327] These measures impose carbon-performance thresholds on materials and buildings, affecting the competitiveness of carbon-intensive materials like clinker-based cement and steel. Biodiversity requirements–such as no-net-loss or net-gain frameworks–and stricter permitting for quarries are altering cost structures and supply options.[328] Together, these dynamics indicate that resilience in BTP requires forward-looking integration of design, materials strategy, subcontractor governance, and digital traceability rather than reactive compliance.

The renovation of existing building stock, often framed primarily as an energy-efficiency measure, carries significantly broader strategic value. The EU's Renovation Wave aims to renovate 35 million building units by 2030, with an estimated creation of 160,000 additional

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[320] Eurostat. (2024). *Housing in Europe – 2025 edition: Construction sector and building permits for dwellings*. European Commission.
[321] OECD. (n.d.). Public investment and infrastructure. In *Effective Public Investment Across Levels of Government*. Organisation for Economic Co-operation and Development.
[322] FIEC. (2025). *FIEC Statistical Report 2025: European Union construction outlook* (European Federation of Building and Woodworkers – FIEC).
[323] Intergovernmental Panel on Climate Change. (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Working Group II contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (H.-O. Pörtner et al., Eds.). Cambridge University Press.
[324] International Labour Organization. (2023). *Safety and health at the heart of the future of work: Building on 100 years of experience*. ILO.
[325] Transparency International EU. (2022). *Exporting corruption: Labour exploitation in construction supply chains in Europe*. Transparency International.
[326] Ministère de la Transition écologique (France). (2022). *RE2020: Réglementation environnementale pour les bâtiments neufs*
[327] European Commission. (2024, July 19).
[328] European Environment Agency & ETC/CE. (2023). *Circular Economy and Biodiversity – EEA/ETC-CE Report 2023/7*.

jobs, largely in local, non-relocatable construction trades.[329] The EU construction sector employs approximately 25 million people across 5.3 million firms, of which 99% are SMEs accounting for 90% of sector employment.[330] [331] Deep renovation creates durable, place-bound employment that strengthens regional economic autonomy and reduces exposure to globalized supply chain disruptions.[332]

From a decarbonization standpoint, renovation addresses the largest share of the sector's emissions: existing buildings account for approximately 75% of the EU's building stock that is not yet aligned with long-term energy performance standards. At current renovation rates (around 0.2% per year for deep renovation), it would take centuries to align the stock with Paris Agreement trajectories. Renovation also generates co-benefits in public health (improved indoor air quality, reduced energy poverty), urban resilience (adaptive reuse of aging structures), and circular economy (extending the material lifespan of existing assets rather than consuming virgin resources for demolition-and-rebuilding cycles).

More broadly, demand-side sobriety, i.e. designing to build less, build smarter, and maximize the useful life of existing assets, is emerging as a structural policy signal across Europe. In France, the "Zéro Artificialisation Nette" (ZAN) objective, enshrined in the 2021 Climat et Résilience law, mandates a halving of land consumption by 2030 and zero net soil artificialization by 2050, directly constraining greenfield construction and redirecting investment toward densification, rehabilitation, and brownfield reconversion.[333] At European level, the 2011 Roadmap to a Resource Efficient Europe recommended a "no net land take" target by 2050, and several member states (Germany, Belgium, Italy) have since adopted equivalent frameworks.[334] [335] These policies reorient the construction value chain toward resource efficiency and land sobriety: less sprawl, less extraction of raw materials, and higher-value use of each square meter built.[336]

Taken together, these evolving regulatory pressures signal a structural shift in the economics of construction, where long-term resilience will depend on anticipating carbon, circularity, and biodiversity requirements upstream rather than treating compliance as a downstream constraint.

Operational levers and industry practices

Financing Sustainable Transitions

Financing sustainable transitions involves addressing the capital constraints of small and medium-sized subcontractors and material suppliers. Several large groups have adopted co-investment and supplier-support models. For example, Holcim has committed to scaling its low-carbon cement (ECOPlanet) and ready-mix concrete (ECOPact) and to deploying its

[329]European Commission. (2020). A Renovation Wave for Europe: greening our buildings, creating jobs, improving lives. COM(2020) 662 final.
[330]OECD. (2022). Decarbonising Buildings in Cities and Regions. OECD Urban Studies.
[331]BUILD UP / European Commission. (2024). Funding building renovations: tackling challenges in the EU's plan for energy decarbonisation. SHERLOCK project.
[332]IHRB. (2024). Human Rights and the Decarbonization of Buildings in Europe.
[333]Loi n° 2021-1104 of 22 August 2021 on combating climate change and strengthening resilience (Climat et Résilience law), Article 191 et seq.
[334]European Commission. (2011). Roadmap to a Resource Efficient Europe. COM(2011) 571 final.
[335]Fnau. (2023). Land sobriety tools in Europe. National federation of urban planning agencies, France.
[336]Cerema. (2024). Reconciling economic development and land sobriety in business zones: a series of experience reports

circular construction platform (ECOCycle) across Europe, thereby offering lower-carbon and recycled-material solutions to clients and subcontractors. Holcim's public "Accelerating Green Growth" strategy integrates these offerings as central to its business model.[337] Similarly, Bouygues Construction operates an internal carbon fund to support investments by its subcontractors in low-emission machinery and site-level energy efficiency.[338] Holcim's "Green Growth Investment Program" dedicates capital to scale low-carbon cement technologies and recycling platforms across Europe (Holcim, 2023). These mechanisms enable upstream decarbonization and reduce dependency on high-carbon materials.

Data, measurement, and compliance

Data, measurement, and compliance are increasingly central to project delivery, as major contractors adopt digital tools for real-time monitoring of environmental and safety metrics. Skanska applies Environmental Product Declarations (EPDs) to track the embodied carbon of materials and has integrated carbon-accounting workflows into its procurement systems.[339] In parallel, Eiffage employs the Sekoya platform to identify and certify low-carbon material innovations, incorporating these solutions into tender responses aligned with EU Taxonomy requirements.[340] Heidelberg Materials has expanded its digital traceability systems for aggregates and concrete, enabling verification of recycled content and strengthening compliance with waste-management regulations.[341] Collectively, these data infrastructures lower verification costs and reinforce accountability across multi-tier supply chains.

Within the Bouygues group, several proprietary digital tools illustrate this integration at operational level. Equans's Smarteo platform enables real-time monitoring of energy consumption, water, compressed air, and greenhouse gas emissions across industrial and building sites, supporting ISO 50001 compliance through automated dashboards and alerts.[342] Bouygues Construction has also deployed a "Calculette bas carbone," an internal lifecycle carbon assessment tool integrated into project workflows to guide material selection and design decisions from the earliest stages.[343] At the infrastructure layer, Bouygues Telecom's private 4G/5G networks and edge computing capabilities support connected site management, from intelligent airport operations to real-time environmental monitoring, extending digital traceability from reporting into day-to-day operational compliance.[344]

Knowledge and capacity building

Capacity and knowledge development have become critical enablers of low-carbon construction, as the transition requires new technical competencies across design, materials selection, and project execution. Small and medium timber builders invest in targeted training to close skills gaps and accelerate technology diffusion: for example, Baufritz operates practical training and knowledge-sharing activities for carpenters, craftsmen, and installation teams focused on prefabricated timber systems and ecological detailing (Baufritz, n.d.)[345].

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[337] Holcim. (2024). *2023 Integrated Annual Report*. Holcim.
[338] Bouygues Construction. (2025, January 16). *Bouygues Construction and Ecocem announce global partnership to reduce the construction industry's carbon impact*. Bouygues Construction press release.
[339] Skanska. (2024). *Annual and Sustainability Report 2024*.
[340] Eiffage. (2024). *2024 Universal Registration Document / Climate Report 2024*. Eiffage.
[341] Heidelberg Materials. (2024, January 30). *Heidelberg Materials launches new global brand for low-carbon and circular products: evoBuild* [Press release]. Heidelberg Materials.
[342] Equans Digital. (2025). *Smarteo, our energy management solution*.
[343] Groupe Bouygues. (2025). Integrated Report 2025
[344] Groupe Bouygues. (2025). Sustainability Stragety, Integrated Report 2025
[345] Baufritz. (n.d.). Baufritz – eco houses and timber construction. Retrieved 2025.

Similarly, KLH Massivholz (a specialist CLT manufacturer and supplier) provides technical support, training sessions, and design guidance for contractors and engineers to ensure correct CLT handling, connections, and moisture management in multi-story timber projects (KLH Massivholz, n.d.)[346]. Academic analyses corroborate that such industry-driven training and close manufacturer–contractor collaboration are critical to achieving the embodied-carbon reductions that timber systems can deliver when combined with good practice in forestry, sourcing, and life-cycle assessment.[347]

Similarly, Eiffage advances sectoral learning through its low-carbon "material mix" framework, which disseminates knowledge on bio-based and recycled materials across project teams and professional networks.[348] Research institutions similarly contribute to knowledge diffusion: INRAE's studies on bio-based construction materials, such as hempcrete, provide validated life-cycle assessment evidence and technical guidance for industry adoption.[349]

Green technology and innovation

Green technology and innovation constitute a core vector of decarbonization. Companies are scaling low-carbon concrete technologies, bio-based insulation, engineered timber, and material circularity. Holcim's "ECOPlanet" range of low-carbon cements demonstrates clinker-reduction strategies at scale. In 2023 Holcim launched a calcined-clay-based cement line at its Saint-Pierre-la-Cour plant in France under its ECOPlanet range – delivering up to 500,000 t/yr of cement with as much as 50% lower CO_2 footprint than standard cement (CEM I), thanks to reduced clinker content and use of alternative raw materials[350]. In parallel, building-materials firms and construction companies are deploying mass-timber (cross-laminated timber, CLT) solutions. For instance, Bouygues Construction completed in 2024, the "Xylo" timber-based office development in Grenoble, using CLT panels and glued-laminated timber, illustrating a move toward engineered-timber construction at meaningful scale.[351]

At the same time, the cement industry is piloting carbon-capture-enabled cement production. Heidelberg Materials has launched evoZero – described as the "world's first carbon-captured net-zero cement." The facility at the company's Brevik plant in Norway is designed to capture 400,000 tons CO_2 per year (about 50% of the plant's emissions).[352] Clients such as Skanska have already committed to using evoZero for upcoming projects. Additionally, electrification of construction machinery is gaining ground. Through a partnership between Volvo Construction Equipment (Volvo CE) and Heidelberg Materials[353], electric loading and hauling vehicles are being introduced across Northern European operations – offering a pathway to reduce CO_2 emissions from transport and site-work activities.

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[346] KLH Massivholz GmbH. (n.d.). KLH – CLT for timber construction. Retrieved 2025

[347] Mouton, L., Trigaux, D., Allacker, K., & Röck, M. (2023). Bio-based building material solutions for environmental benefits over conventional construction products: Life cycle assessment of regenerative design strategies (1/2). *Energy and Buildings, 282*, 112767.

[348] Eiffage. (2023). *Low carbon construction: A low-carbon "material mix"*.

[349] INRAE. (2025). *Biobased construction materials: A sustainable solution?*

[350] Holcim. (2023, February 13). *Holcim launches Europe's first calcined clay low-carbon cement operation*. Holcim Media Releases.

[351] Bouygues Construction. (2024). *Xylo tertiary wood building*. Bouygues Construction.

[352] Heidelberg Materials. (2025, October 17). *evoZero® hits the market: World's first carbon captured cement delivered to customers across Europe*. Heidelberg Materials Press Release.

[353] Volvo Group & Heidelberg Materials. (2023, June 20). *Volvo Group partners with Heidelberg Materials to reduce emissions in construction industry*. Volvo CE News.

Beyond material substitution and machinery electrification, eco-design for reparability, modularity, and deconstructibility is gaining traction as an operational lever. The forthcoming EU Ecodesign for Sustainable Products Regulation extends lifecycle requirements to construction products,[354] while the Buildings as Material Banks (BAMB) research program has promoted reversible building design: structures conceived from inception for disassembly, component reuse, and adaptation to changing functions.[355] Design for Deconstruction (DfD) remains marginal (fewer than 1% of buildings globally are designed for full disassembly), but regulatory momentum and pilot projects are shifting this trajectory.[356]

Hybridization of building uses, i.e. designing structures that can alternate between residential, office, and commercial functions across their lifecycle, reduces net construction demand and increases the useful value per square meter of built space. Modular construction systems, prefabricated timber and steel frames, and reversible partition technologies enable such flexibility. In Germany, the EDGE Suedkreuz Berlin project, a 20,000 sqm timber hybrid office complex, was designed with a full material passport on the MADASTER platform, enabling future reuse and recycling of all construction components.[357]

In practice, DfD involves the use of mechanical (bolted, clipped) rather than chemical (glued, welded) connections, standardized component dimensions, and material passports that document composition, origin, and reuse potential. The EU-funded RECONSTRUCT project is developing recyclable concrete and designing two fully circular buildings in Barcelona and Brussels, with 6D-BIM digital twins to guide future deconstruction procedures.[358] [359] These approaches reduce construction and demolition waste, currently the EU's largest waste stream at approximately one-third of all waste generated, and create the conditions for a secondary materials market that reduces dependency on virgin extraction.[360]

Waste management and resource efficiency

Waste management and resource efficiency have become critical components of sustainable construction, driven by both regulatory pressures and the significant volume of construction and demolition waste (CDW), which constitutes over a third of all waste generated in the European Union (European Commission, n.d.). Leading construction firms have increasingly implemented circular-economy strategies to address these challenges. Eiffage, for instance, employs systematic on-site sorting, selective deconstruction, and recycling of materials such as concrete and aggregates, allowing recovered materials to be reintegrated into new construction projects.[361]

Similarly, VINCI Construction operates material-recovery platforms and specialized processing plants to treat contaminated soils and transform them into reusable construction materials,

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[354]European Commission. (2022). *Proposal for a Regulation establishing a framework for setting ecodesign requirements for sustainable products (Ecodesign for Sustainable Products Regulation)*.
[355]BAMB (Buildings as Material Banks). (2021). Reversible Building Design protocols. EU Horizon 2020 project.
[356]Munaro, M.R., Tavares, S.F. & Bragança, L. (2022). *The ecodesign methodologies to achieve buildings' deconstruction: A review and framework*
[357]EDGE Technologies / MADASTER. (2023). *EDGE Suedkreuz Berlin: Material passport and Design for Deconstruction case study.*
[358]European Commission. (2020). *Circular Economy Action Plan: For a cleaner and more competitive Europe. COM(2020) 98 final.*
[359]RECONSTRUCT. (2024). *Circular territorial solutions for the built environment. EU Horizon Europe project*
[360]European Commission. (n.d.). *Construction and demolition waste. Eurostat / Waste Statistics.*
[361] Eiffage. (2025). *Circular economy: A strategy in motion*.

while its Granulat+ program supplies aggregates that incorporate recycled content, reducing reliance on virgin resources.[362]

A concrete illustration of this circular economy logic is Cyneo, a subsidiary launched by Bouygues Construction in 2023 to structure and scale the reuse of construction materials in France.[363] Cyneo operates a network of technical centers (the first opened at Vitry-sur-Seine in Île-de-France, 2,700 sqm, followed by Nantes, 3,500 sqm, in 2025 and Lille in 2026) that provide shared storage, production, prototyping, and showroom space to enterprises specializing in the reconditioning and resale of building components such as doors, sanitary equipment, floor coverings, cladding, and windows.[364] The initiative connects over 80 member companies and partners including Saint-Gobain, Valobat, and SMABTP, and offers training, regulatory guidance, and a digital marketplace linking supply from deconstruction sites to demand on new projects.[365]
Each year in France, the building industry generates 46 million tonnes of waste, of which an estimated 80% could be reused, yet only around 1% currently is. Cyneo's model, open to competitors (including Vinci subsidiaries such as Circable), illustrates how structured intermediation and technical standardization can overcome the fragmentation, insurance, and quality barriers that have historically constrained material reuse at scale.[366]
Within the Bouygues ecosystem, Colas has developed complementary circular and resource-efficiency solutions for road and civil engineering. Its subsidiary Tersen operates the Valormat and Ecotri recycling network, with a target of 400 platforms nationwide, producing the ECOSOL range of recycled materials (ECOSOL Chaux for embankments, ECOSOL Fertile for landscaping, ECOSOL Béton for self-compacting concrete) from excavated soils and demolition waste, achieving a 47% carbon reduction compared to standard concrete equivalents.[367] Colas currently produces 7 million tonnes of recycled aggregates per year in France and aims to reach 10.5 million by 2026.[368] On water management, Colas's permeable pavement solutions, including reservoir pavement structures, enable on-site stormwater infiltration, storage, and reuse, reducing runoff and alleviating pressure on urban drainage infrastructure.[369] At the building-systems level, Equans's HEATEO platform combines waste heat recovery, thermal storage, and low-carbon heat production across interconnected assets — in a notable example in Rotterdam, industrial waste heat is captured and transported over 10 km to supply 120,000 households in The Hague.[370]

CRH Group has also institutionalized circular construction practices across Europe, processing millions of tons of CDW in its recycling centers to produce recycled aggregates and ready-mix concrete for new projects, thereby decreasing extraction pressure on quarries and supporting compliance with emerging EU directives on recycled content.[371] Collectively, these practices demonstrate how construction firms are integrating resource efficiency into

[362] VINCI Construction. (2025). *Optimising resources thanks to the circular economy*. VINCI.
[363] Bouygues Construction. (2023). Bouygues Construction invests in the reuse market by creating Cyneo and the first technical center for construction material reuse
[364] Construction21. (2024*). Cyneo technical center at Les Ardoines*.
[365] Le Moniteur. (2026, February 18). Construction material reuse: in Lille, Bouygues opens a third Cyneo location
[366] Le Journal des Entreprises. (2025). In Nantes, Cyneo aims to structure the construction material reuse sector.
[367] Environnement Magazine. (2025). *Tersen fait germer les terres excavées en Ile-de-France*
[368] Colas. (2025). Press release : *Economie circulaire, Colas lance le réseau de plateformes Valormat et Ecotri*
[369] Colas. *Raincol : Enrobé drainant pour parkings perméables*
[370] Equans. *HEATEO: Unlock the full potential of thermal energy*
[371] CRH. (2023). *Sustainability report 2023*. CRH Group.

operational strategies, promoting a circular approach that reduces environmental impacts, maximizes material reuse, and aligns with evolving regulatory requirements.

Governance and collaboration models

Governance and collaboration models in sustainable construction are evolving through multi-stakeholder alliances, long-term supplier frameworks, public-private partnerships, and sector-wide initiatives that go beyond transactional subcontracting. For instance, the Supply Chain Sustainability School[372] in Ireland – launched in 2024 – is an industry-wide, cross-company platform that brings together over 500 companies in the built-environment sector to train staff and suppliers on sustainability practices. Through shared procurement standards and joint training, the initiative builds common capacity in sustainable supply chains.

In another case, the ArcelorMittal steel company has partnered with a building-systems manufacturer, BP2, to supply low-carbon steel (produced under its XCarb® program) for photovoltaic roof solutions – a supply-chain level collaboration that aligns material production with low-carbon building goals[373]. This shows how material suppliers and building-product manufacturers can form purposeful alliances to decarbonize the upstream supply chain. Multi-corporate innovation matchmaking is another emerging model: in 2025, the European Innovation Council (EIC)[374] brought together major construction and infrastructure firms – including Ferrovial, Acciona, ACS, Sacyr and VINCI – with start-ups supported by the EIC to co-develop and pilot innovative infrastructure solutions. This model distributes R&D risk across incumbents and innovators, accelerates technology diffusion, and fosters shared governance of innovation pipelines.

On the public-private side, recent infrastructure projects under the legacy of the Paris 2024 Olympic and Paralympic Games[375] illustrate collaboration between public authorities and private constructors. For example, the client – SOLIDEO – partnered with a major construction firm to deploy ultra-low-carbon concrete for buildings, even before formal certification. This advance was enabled by shared risk, public funding support, and joint decision-making – showing how public-private governance can enable early adoption of low-carbon innovations.

Overall, these examples show that effective governance and collaboration models in sustainable construction can take various forms – from industry-wide training platforms, cross-chain supplier partnerships, public-private innovation programs, to coalitions that integrate material producers, contractors, developers and authorities. By distributing costs, sharing risk, and aligning incentives across stakeholders, these models help embed sustainability more deeply and systematically across the construction value chain.

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[372] Irish Construction. (2025). *Driving sustainability through collaboration: Free summit marks one year of impact*. Supply Chain Sustainability School.
[373]ArcelorMittal & BP2. (2023). *Successes for sustainable construction at BAU*. Constructalia / ArcelorMittal.
[374] Acciona, Ferrovial, ACS, Sacyr, & VINCI. (2025, June 4). *The EIC connects construction leaders to build tomorrow's infrastructure*. European Innovation Council.
[375] OECD. (2025). *The legacy of the Paris 2024 Olympic and Paralympic Games: Upping the game – Responsible Games: improving sustainability through infrastructure and procurement*. OECD Publishing.

Operational levers and industry practices in the construction sector

Category	Operational Lever / Practice	Description	Example(s)
1. Financing Sustainable Transitions	Shared investment in SME upgrades	Large construction firms co-invest with subcontractors and material suppliers to enable adoption of low-carbon technologies, circular production methods, and traceability infrastructure	Holcim ECOPlanet, ECOPact, and ECOCycle deployment; Bouygues internal carbon fund supporting low-emission machinery
	Micro-grants & low-interest loans	Financial support to small-scale suppliers to implement energy-efficient processes or new sustainable materials	Holcim Green Growth Investment Program providing capital to scale low-carbon cement and recycling platforms
2. Data, Measurement, and Compliance	Traceability and product registration	Digital platforms and workflows track materials, sourcing, and sustainability metrics to ensure regulatory compliance and accountability	Skanska Environmental Product Declarations (EPDs) for embodied carbon; Heidelberg Materials digital traceability systems for aggregates and concrete; Bougyues' "Calculette bas carbonne" its internal LCA tool integrated into project workflows
	Environmental monitoring & reporting	Track energy, water, material waste, and emissions in real time; supports ESG reporting and process optimization	Skanska carbon-accounting workflows; Eiffage Sekoya platform for low-carbon material innovation; Smarteo (Equans) and Datawatcher (Bouygues Construction) real-time energy monitoring platforms
	Supplier codes & auditing	Establish supplier standards and codes of conduct, coupled with audits, to ensure environmental and social compliance	Skanska preferred-supplier frameworks with shared safety, carbon, and performance KPIs
	Smart infrastructure and connectivity	Use of digital infrastructure to optimize operations and ensure compliance	Bouygues Telecom private 4G/5G networks and edge infrastructure for connected site management and real-time compliance monitoring
3. Knowledge and Capacity Building	Supplier training	Upskilling SMEs and subcontractors in sustainable construction techniques, materials handling, and low-carbon practices	Baufritz practical training for carpenters and craftsmen on prefabricated timber systems; KLH Massivholz CLT technical support and design guidance
	Cross-functional innovation partnerships	Collaboration among contractors, suppliers, and research institutions to co-develop sustainable materials or low-carbon technologies	Eiffage low-carbon "material mix" framework; INRAE studies on hempcrete and bio-based materials

	Eco-design programs	Integrate sustainability principles in project design and construction, and disseminate knowledge across teams	Eiffage “Sekoya” platform; Bouygues Xylo timber-based office development
4. Green Technology and Innovation	Material substitution	Replace high-impact materials with low-carbon, bio-based, recycled, or engineered alternatives	Holcim ECOPlanet clinker-reduced cement; Bouygues Xylo CLT panels; Heidelberg Materials evoZero carbon-capture cement
	Sustainable infrastructure	Implement low-impact, energy-efficient construction methods and electrified machinery	Electrification of construction machinery via Volvo CE and Heidelberg Materials partnership
	Circular product design	Design materials and components for reuse, recycling, or longevity	Holcim ECOCycle circular construction platform;
	Design for deconstruction and modularity	Design buildings for future disassembly, component reuse, and use-case flexibility through mechanical connections, standardized dimensions, and material passports	EDGE Suedkreuz Berlin (20,000 sqm timber hybrid with full MADASTER material passport for future reuse); EU RECONSTRUCT project (two fully circular buildings in Barcelona and Brussels with 6D-BIM digital twins)
5. Waste Management and Resource Efficiency	Upcycling and scrap utilization	Recover construction and demolition waste (CDW) and reintegrate it into production to minimize virgin material extraction	CRH recycling centers producing aggregates and ready-mix concrete; Eiffage on-site sorting and recycling; Tersen/Colas ECOSOL range (recycled materials from excavated soils and demolition waste, 47% carbon reduction vs. standard concrete); Colas Valormat and Ecotri recycling network (7 Mt/yr recycled aggregates, target 10.5 Mt by 2026)
	Circular supply chains	Establish systems for take-back, reuse, and recycling of materials	VINCI Construction Granulat+ program for recycled aggregates; CRH Group circular construction practices across Europe; Cyneo (Bouygues Construction subsidiary; network of technical centers for material reuse in Vitry-sur-Seine, Nantes, and Lille; 80+ member companies including Saint-Gobain and Valobat; digital marketplace and training); Colas Raincol permeable asphalt for stormwater infiltration; Equans HEATEO platform for waste heat recovery, thermal storage, and low-carbon heat production across interconnected assets

	Community engagement	Collaborate with local authorities and communities for responsible waste management	Paris 2024 Olympic infrastructure projects (SOLIDEO partnership with private constructors for low-carbon concrete)
6. Governance and Collaboration Models	Multi-stakeholder consortiums	Cross-company alliances to share infrastructure, data platforms, or R&D, scaling sustainability efforts	Supply Chain Sustainability School (Ireland) with 500+ companies; ArcelorMittal XCarb® collaboration with BP2; Cyneo open-membership model
	Collaborative infrastructure	Shared facilities or labs co-funded by multiple actors to pilot low-carbon technologies	EIC innovation matchmaking program (Ferrovial, Acciona, ACS, Sacyr, VINCI, and start-ups)
	SME partnerships	Integrate SMEs into supply chains with sustainability and circularity practices	Holcim and Bouygues supplier-support initiatives; Skanska preferred-supplier programs
	Pre-competitive innovation platforms	Open-access platforms for competitors to co-develop sustainable materials and technologies	Eiffage Sekoya low-carbon materials club; European Innovation Council (EIC) infrastructure innovation pilots

Exhibit 38 – Source: Ardabelle Capital interviews and analysis

Focus box: Modern Methods of Construction as a decarbonization accelerator

Modern Methods of Construction (MMC) – off-site manufacturing and modular building systems – function as an integrative lever for sectoral decarbonization by enabling systematic deployment of technologies that remain difficult to scale through fragmented on-site practices. Factory-based production facilitates standardized incorporation of low-carbon materials (engineered timber, bio-based insulation, low-carbon concrete) while providing the organizational infrastructure for digital traceability, Environmental Product Declarations, and material passports at scale. Standardization drives cost reduction through volume economies (typically 5–10 percent per production doubling), absorbing cost premiums associated with sustainable materials and accelerating market diffusion.

MMC platforms also address the skills gap through factory-based training, reduce exposure to global supply-chain volatility via regional hubs, and anchor domestic processing capacity for bio-based materials. However, successful deployment requires sustained demand visibility and cross-stakeholder collaboration: high-profile failures (Katerra, Ilke Homes) contrast with cases achieving scale through long-term partnerships with public procurers and material suppliers (Lindbäcks Modular, Stack Modular). Recent investments by major construction groups (Bouygues, Saint-Gobain, Goldbeck) and emerging procurement frameworks favoring standardized low-carbon systems signal growing institutional recognition of MMC's strategic role.

Conclusion

In summary, the construction industry is leveraging a diverse set of operational levers to drive sustainable transitions. From financing mechanisms that enable SMEs to adopt low-carbon technologies, to digital data platforms ensuring traceability and compliance, and knowledge-sharing initiatives that build sector-wide capacity, these practices collectively advance

decarbonization and circularity. Green technology adoption, waste management strategies, and collaborative governance models further reinforce systemic change, enabling firms to reduce environmental impacts while maintaining competitiveness. The integration of these levers demonstrates that coordinated, multi-stakeholder approaches are essential for embedding sustainability across the construction value chain and achieving long-term climate-aligned outcomes.

Defense

Defense supply chains are inherently opaque, shaped by stringent security requirements, confidentiality obligations, and classified procurement processes that limit the visibility of supplier relationships and internal capability-building activities. Much of the ecosystem operates behind restricted access portals, non-disclosure agreements, and export-control constraints, meaning that practices such as supplier training, digital-readiness programs, or traceability initiatives are often carried out internally by primes but not publicly documented. As a result, any deep-dive analysis must rely on the limited information that is available in open sources–press releases, official procurement statements, regulatory documents, and occasional case studies–while recognizing that these provide only a partial view of the full landscape.

Overview of risks and materiality

In 2024, the Ukrainian government experienced a major disruption in its defense procurement. Amid the conflict with Russia, it advanced approximately $770 million to foreign intermediaries for ammunition and military equipment. Many shipments never arrived, and some were unusable upon delivery. Notably, a €17.1 million contract with OTL Imports in Arizona resulted in no deliveries, triggering legal disputes, higher costs, and significant erosion of trust in the procurement process.[376] As this event demonstrates, shocks in the defense sector carry extremely high material consequences, making resilience not optional but an essential strategic imperative.

The defense sector encompasses military equipment manufacturers, technology developers, contractors, and service providers. Unlike consumer industries, it is defined by high technological complexity, extensive regulatory oversight, and acute geopolitical sensitivity. Core risks include operational security, supply chain fragility, regulatory compliance, cyber threats, reputational exposure, and exposure to geopolitical volatility. Defense products are mission-critical, often dual-use, and carry national security implications, which amplify both operational and ethical stakes. The sector's vulnerabilities converge around supply chain dependency, technological integrity, and geopolitical exposure. Many defense systems rely on specialized components–rare earths, microelectronics, or high-performance alloys–often sourced globally, creating structural dependencies sensitive to disruption.[377] Emerging regulations on arms exports, environmental compliance, and labor rights further impose operational constraints with legal and reputational consequences.

Environmental and social dimensions are increasingly material. Defense manufacturing is energy- and resource-intensive, with steel, rare earth elements, and electronics dominating Scope 3 emissions[378]. Ethical concerns around arms proliferation, forced labor, and conflict minerals expose firms to reputational and regulatory risk, making upstream supplier engagement a strategic imperative. Cybersecurity is another critical dimension. Defense Industrial Base (DIB) contractors face persistent threats, including espionage and ransomware,

[376] Perepechko, I. (2025, May 16). *FT: Ukraine paid $770 million for weapons it never received. Financial Times*
[377] Air University. (2023). *Causes of vulnerabilities and key threats to defense supply chains.*
[378] PwC. (2022). *Defense supply chains: Managing risks and sustainability*

which can disrupt operations, compromise intellectual property, and create cascading risks across global supply chains[379].

Taken together, these dynamics show that risk in Defense is highly concentrated upstream, in sub-tier suppliers and global supply chains, and is intertwined with both operational and strategic exposure. Effective risk management requires robust supplier engagement, due diligence on minerals and labor, cyber risk mitigation, and attention to environmental and Scope 3 impacts, reflecting a convergence of operational resilience and compliance imperatives.

Some defense top players have already formalized this convergence at the strategic level. Thales, for instance, positioned sustainability as a core pillar of its 2030 strategic plan and restructured its governance accordingly in 2022, creating an integrated CSR directorate and appointing CSR correspondents at the level of strategy and marketing directors across its global activities. In 2024, the group reinforced this with nine commitments structured across three pillars (Society, Planet, Employees), embedding sustainability into strategic planning rather than treating it as a compliance overlay. As Thales' CEO Patrice Caine stated publicly in 2022: defense and sustainability are intrinsically linked, since there is no sustainability without stability.[380]

Supply chain security and critical components

Defense products depend heavily on highly specialized components–such as microelectronics, advanced alloys, and high-performance batteries–that are often sourced from single suppliers. This reliance creates significant vulnerabilities, as disruptions–whether due to geopolitical tensions, natural disasters, or supplier insolvency–can delay program delivery, inflate costs, and compromise operational readiness. The U.S. Department of Defense (DoD)[381] has identified these supply chain fragilities as a critical concern. The 2022 report *Securing Defense-Critical Supply Chains* highlights persistent vulnerabilities in sub-tier suppliers, including shortages of raw materials and critical subcomponents produced by fragile suppliers. The report notes that the DoD has limited visibility into these sub-tiers, which impedes effective risk management and timely delivery of essential components.

Thales has operationalized this concern by mapping the resilience of its assets and business model to both climate change and critical raw materials (CRM) sourcing risks. The group extends its supply chain knowledge beyond Tier 1 to verify or ensure resilience to geopolitical risks and supports where needed the establishment of European recycling capacity for strategic materials. A dedicated task force within the Procurement directorate, mirrored by strategy and business oversight, works to secure CRM supply over multi-year horizons. Concrete actions include developing a European recycling pathway for Germanium used in infrared optics, and qualifying recycled titanium at quality levels equivalent to virgin materials.[382]

[379] BlueVoyant. (2021, June 22). *Defense Industry Supply Chain & Security 2021 report: Cyber-security weaknesses within the defense industrial base supply chain*.
[380] Thales. (2025). Universal Registration Document 2025
[381] Department of Defense. (2022). *Securing defense-critical supply chains* (Phase I report). Office of the Assistant Secretary of Defense for Sustainment.
[382] Thales. (2025). Universal Registration Document 2025; Integrated Report 2025

Geopolitical and export controls and sustainability risks

Defense companies operate under intricate export control regimes, including the U.S. International Traffic in Arms Regulations (ITAR), Export Administration Regulations (EAR), and the European Union's dual-use export controls. Violations of these regulations can result in severe consequences. For instance, under ITAR, criminal penalties can include fines up to $1 million per violation and imprisonment for up to 20 years, while civil penalties can reach up to $500,000 per violation.[383] Similarly, the EU's dual-use export controls impose fines ranging from 1% to 5% of a company's total worldwide turnover or fixed penalties between €8 million and €40 million for breaches.[384] These stringent measures underscore the critical importance of compliance in the defense sector.

Geopolitical risks are inherent, as sanctions, trade restrictions, and conflicts can abruptly disrupt supply chains or diminish demand for products. For example, in 2024, RTX (formerly Raytheon Technologies) agreed to pay $200 million to settle allegations of violating U.S. export controls by transferring sensitive technology to China. This settlement highlights the significant financial and reputational repercussions of non-compliance.[385] People feel clearly concerned about this way of thinking sovereignty. More than half of Europeans in Europe say they would be willing to pay more for technology if it were developed, owned, or operated by a domestic company[386] and this figure increases when we focus on the defense sector.

Environmental impacts in the defense sector are predominantly upstream, encompassing mining, energy-intensive manufacturing, and logistics, which contribute significantly to Scope 3 emissions. According to PwC, Scope 3 emissions can account for up to 95% of a company's total carbon footprint, making them a critical focus for sustainability efforts.[387] Social risks are concentrated in labor practices associated with raw material extraction, particularly concerning rare earth elements and conflict minerals. The U.S. Department of Labor has reported instances of child and forced labor in critical mineral supply chains, necessitating thorough risk assessments and the implementation of comprehensive strategies to mitigate these risks[388]. Governance risks arise from ethical considerations surrounding arms sales, compliance with international treaties, and anti-corruption practices. The International Committee of the Red Cross emphasizes that providing weapons to parties involved in armed conflict can result in criminal liability under international law if those weapons are used to commit war crimes or other international crimes.

Cybersecurity and industrial espionage

The defense sector faces significant cybersecurity challenges, particularly concerning Advanced Persistent Threats (APTs) targeting critical technologies such as artificial intelligence (AI), hypersonic, and next-generation avionics. These threats are often state-sponsored and aim to infiltrate contractors' supply chains to steal sensitive data or disrupt operations. For example, in 2024, North Korean-backed hackers launched a global cyber-espionage campaign targeting military and aerospace sectors, compromising data related to satellites, submarines,

[383] McKonly & Asbury LLP. (n.d.). *CMMC Third-Party Assessment Organization (C3PAO)*.
[384] Clevr. (n.d.). *Dual-use compliance in aerospace and defense: What you need to know.*
[385] The Wall Street Journal. (2024, March 1). *RTX to pay $200 million over export control violations.*
[386] Putois, C. (2025, September 25). *Les citoyens veulent-ils vraiment de la souveraineté numérique ? 10 points sur une enquête mondiale*. Le Grand Continent.
[387] PwC. (n.d.). *Scope three challenge: Addressing upstream and downstream emissions.*
[388] U.S. Department of Labor. (n.d.). *From mines to markets: Exposing labor exploitation in critical mineral supply chains*

and nuclear technology[389]. Similarly, Chinese cyber espionage efforts have intensified, with reports of sustained intrusion attempts against Dutch defense industries, including aerospace and maritime sectors[390]. These incidents underscore the urgent need for robust cybersecurity measures within the defense industrial base.

Operational Levers and Industry Practices

In the defense sector, small and medium-sized enterprises (SMEs) and niche suppliers are indispensable. These specialized producers–ranging from electronic components and advanced alloys to software modules–possess unique technical expertise that is often irreplaceable. Their operational and financial fragility can significantly impact the resilience of larger contractors.

Transition financing

Mobilizing both public and private capital is essential to strengthen the defense supply chain's sustainability and resilience. Financing mechanisms–such as supplier co-investment schemes, blended finance, and advance payment models–allow SMEs to modernize facilities, achieve certifications, and adopt low-carbon technologies that would otherwise be beyond their financial reach. A strong example comes from BAE Systems and MBDA, who partner with the UK Ministry of Defense under the Defense Technology Exploitation Program (DTEP). This initiative provides matched funding of up to £500,000 per SME to accelerate the development of innovative technologies with direct application in defense programs.[391] Primes like BAE and MBDA co-invest not just financially but through technical mentorship, R&D collaboration, and access to procurement pathways, helping smaller firms bring their innovations to market. This model represents a form of shared-risk financing–where government, primes, and SMEs all contribute resources to strengthen technological capability and supply-chain resilience. It goes beyond simple supplier contracting: BAE and MBDA actively enable SMEs to scale innovation, diversify revenue streams, and meet the stringent quality and cybersecurity standards of defense projects. By lowering financial barriers and encouraging technological diffusion, such programs enhance both industrial sovereignty and sustainability. In short, Transition Financing in defense is not limited to traditional lending; it is increasingly about *co-creation and capability investment*.

Data and traceability

Supply chain visibility is critical to managing both operational risk and ESG performance. Digital traceability platforms–integrating blockchain, AI, and secure cloud infrastructures–enable defense primes to monitor supplier compliance, carbon footprints, and ethical sourcing in real time. BAE Systems Australia, for example, adopted Ivalua's Source-to-Pay digital platform to modernize its procurement ecosystem, standardize supplier management, and enhance traceability across more than 1,600 suppliers.[392] This digitalization not only streamlines oversight but also improves transparency around sustainability, risk, and performance data. In parallel, Thales[393] has developed the "Carbon Supply Tracker" application, which enables

[389] The Guardian. (2024, July 25). *North Korea-backed cyber-espionage campaign targets UK military*.
[390] Reuters. (2025, May 31). *Chinese spying on Dutch industries intensifying, Dutch defense minister says*.
[391] Ministry of Defense. (2022, July 27). *Launch of new innovative defense program backed by £16 million: Grants of up to £500,000 available per project*. GOV.UK.
[392] Ivalua. (2024). *Ivalua software to modernise BAE Systems Australia spend management*
[393] Thales. (2024). *Thales innove avec le Carbon Supply Tracker pour réduire l'empreinte écologique de ses projets*

dynamic analysis of data flows across its entire supply chain – from logistics and transport to stock management and partner emissions. The tool is designed to assess in real-time the carbon footprint of upstream suppliers and logistical flows and aims to reduce emissions by 10-15% over five years. Moreover, Thales partnered with Capgemini[394] and Sweep (software company) in 2025 to implement a sustainability-data management platform across its extensive supplier network, targeting reduction of Scope 3 emissions by improving data collection, traceability and engagement throughout its supplier base.

Capacity building

Technical enablement underpins supply chain resilience. Supplier training academies, digital learning portals, and mentorship programs are now standard practice among defense primes to equip SMEs with the tools to meet cybersecurity, environmental, and quality standards. Lockheed Martin's Supplier Training Excellence Program (STEP) offers a virtual suite of learning resources and webinars to help small enterprises achieve compliance and continuous improvement in areas such as cybersecurity and process control.[395] Similarly, BAE Systems' Partnering4Success initiative provides supplier capability assessments and joint problem-solving workshops to enhance SME readiness for complex defense contracts. These collaborative efforts strengthen the ecosystem's ability to absorb shocks, maintain operational integrity, and embed sustainability principles into production and logistics.[396]

Another key actor of the industry, Thales, extends this logic through several structured initiatives. The Pacte PME "Alliance for Decarbonization and Energy Transition" facilitates the decarbonization of French SMEs and mid-cap suppliers.[397] In parallel, Thales has identified over 25 flagship solutions (projects and products) for joint eco-design reflection with suppliers, driving collaborative Scope 3 reduction. At the sectoral level, Thales is an active supporter of Aero Excellence, a universal maturity framework for operational excellence,[398] environmental sustainability, and cybersecurity in aerospace and defense, developed alongside Airbus, Dassault Aviation, and Safran. Thales also co-founded AirCyber, a cybersecurity maturity standard managed by BoostAeroSpace[399] (a joint venture of Airbus, Dassault Aviation, Safran, and Thales), which since 2019 has helped over 430 companies improve their cyber-resilience to bronze, silver, or gold levels.

Green technologies and innovation

Decarbonizing defense operations depends on upstream innovation. Additive manufacturing, hybrid propulsion, and energy-efficient production systems are transforming both performance and environmental impact. Lockheed Martin's expansion of its additive manufacturing facility in Grand Prairie, Texas, illustrates this transition: by 3D printing missile components such as guidance housings and tail fins, the company achieved tenfold reductions in lead times and 90% material savings compared to traditional methods.[400] BAE Systems is similarly advancing sustainable manufacturing through investments in energy-efficient shipbuilding for the Hunter-

[394] Thales; Capgemini Invent; Sweep. (2025). *Thales accelerates supply chain decarbonization with Sweep and Capgemini Invent*
[395] Lockheed Martin. (2024). *Supplier Training Excellence Program (STEP)*
[396] BAE Systems Australia. (2024). *Partnering4Success: Supplier development and relationship-management program*
[397] Thales. (2025). Universal Registration Document 2025
[398] Aero Excellence International. Aero Excellence maturity framework
[399] BoostAeroSpace. AirCyber: Cyber resilience for the aerospace supply chain
[400] Lockheed Martin. (2024). *Additive manufacturing expansion helps meet demand for advanced capabilities*

class frigates in Adelaide, supported by Australian SMEs producing modular components off-site to reduce emissions and logistics intensity[401]. These examples show how technological innovation drives both competitiveness and sustainability across defense production networks.

Thales contributes to green innovation both in commercial aviation and in product lifecycle management. In an operational trial with airline Amelia, Thales' flight path calculator was used to reroute flights around atmospheric zones prone to contrail formation, avoiding between 2,000 and 2,500 tonnes of CO2 equivalent and reducing the average climate impact per contrail-generating flight by over 65%.[402] On the product side, Thales improves reparability as a design objective: at its Trixell subsidiary (digital detectors for medical imaging), the reparability rate has increased by nearly 20 percentage points over the past decade (from 68% to 86%), supported by the growing reuse of reconditioned components in after-sales repairs. More broadly, Thales applies eco-design systematically through internal tools such as CLOE (Eco-design Orientation Checklist) and PETER (simplified product environmental assessment), supported by trained engineering teams and a network of eco-design referents.[403]

Waste management and resource efficiency

Circularity and resource efficiency are gaining strategic relevance in defense manufacturing. Reuse of critical materials, remanufacturing, and closed-loop logistics minimize waste and improve self-sufficiency. Lockheed Martin's 2024 Sustainability Performance Report[404] highlights its efforts to trace upstream origins of critical minerals and integrate supplier sustainability assessments through the International Aerospace Environmental Groups EcoVadis framework–a key step toward responsible material use and recycling. Airbus Defense and Space[405] similarly reports significant progress in closed-loop aluminum recycling, recovering up to 90% of production scrap for reuse in new aircraft components.

Thales applies circular economy principles both in production and in end-of-life management. At Trixell, significant industrial investments have been made to establish a recycling line for cesium iodide used in scintillator manufacturing (consumed at several tonnes per year). The objective is to recycle process effluents and recover 75% of the material, reducing the product's lifecycle environmental impact by 30%. More broadly, Thales' CRM strategy combines traceability, eco-design, and circularity: the group aims to reduce usage of critical metals, integrate recycled materials, identify substitutes, and facilitate end-of-life recovery from waste and production surplus. Initiatives include the development of a European germanium recycling pathway for infrared optics and the qualification of recycled titanium at specifications equivalent to virgin materials. The circular design approach extends to defense systems with long service lives (up to 40 years), through Maintenance, Repair and Overhaul (MRO) activities and programs such as NewCORE, which modernizes military sonars by reusing existing components, reducing cost, installation time, and material consumption. The EOLE tool supports end-of-life decision-making for each system.[406]

[401] BAE Systems Australia. (2024). *Supporting Hunter Class suppliers to embrace smart technology*
[402] Thales. (2025). Press release: Amelia and Thales announce the success of the large-scale deployment of their contrail avoidance project
[403] Thales/ (2025). Integrated Report 2025
[404] Lockheed Martin corporation. (2024). *2024 Sustainability Performance Report*
[405] Airbus SE. (2025). Waste not, want not: Increasing titanium and aluminum circularity. *Airbus Newsroom*
[406] Thales. (2025). Integrated Report 2025

These initiatives demonstrate how waste minimization and resource efficiency enhance both sustainability and supply chain security.

Governance and collaboration

A shift from transactional oversight to relational governance is redefining defense supply chains. Long-term partnerships, joint R&D, and shared cybersecurity frameworks build trust and system resilience. BAE Systems' Partner2Win[407] program exemplifies this transformation: in 2024, it recognized over 90 suppliers for excellence in delivery, quality, and innovation, fostering a culture of mutual accountability and best-practice sharing. Likewise, Lockheed Martin's STAR Supplier Program[408] recognizes companies such as M-Tron Components for meeting exceptional standards in quality and operational excellence, reinforcing collaborative performance improvement rather than punitive auditing. These programs show that governance in modern defense supply chains is no longer about policing compliance but about co-developing standards of sustainability, security, and innovation that align strategic and ethical goals.

Thales reinforces this relational governance model through several mechanisms. Since 2023, a new "Extra-financial Performance / CSR" criterion has been integrated into supplier selection, representing 15% of the overall evaluation score and rewarding commitments on CO2 reduction, eco-responsible design, ISO certifications, inclusion, diversity, and cybersecurity. The group also holds the French "Responsible Purchasing and Supplier Relations" label (ISO 20400), based on principles of purchasing responsibility, supplier relationship quality, protection of supplier interests, and integration of social responsibility into procurement. On the innovation front, Thales has over the past decade referenced more than 3,000 startups and completed nearly 270 proofs of concept, developing synergies with both large industrial groups and entrepreneurial innovators.[409]

[407] BAE Systems, Inc. (2024). *BAE Systems announces top suppliers at sixth annual 'Partner2Win' supplier symposium* [Press release]. PR Newswire.
[408] Lockheed Martin Corporation. (n.d.). *Lockheed Martin selects M-TRON Components as STAR Supplier*
[409] Thales. (2025). Universal Registration Document 2025 ; Integrated Report 2025

Operational levers and industry practices in the defense sector

Category	Operational Lever / Practice	Description	Defense-Sector Example(s)
0.Risk mapping & management	Climate and supply chain resilience mapping	Identification and prioritization of physical, geopolitical, and sourcing risks	Thales: climate resilience mapping of assets and business model; proprietary physical risk tool for supply chain; dedicated CRM task force securing multi-year supply (germanium, titanium)
1. Transition Financing	Co-investment & matched-funding programs	Financial support enabling SMEs to modernize facilities, certify processes, and develop defense-grade technologies	BAE Systems & MBDA + UK MoD DTEP: Matched funding up to £500,000 per SME for tech innovation and industrial capability
	Advance payments & shared-risk financing	Reduce financial barriers for SMEs supplying critical components	Used across UK and EU defense procurement (publicly referenced in DTEP design principles)
2. Data, Measurement & Traceability	Digital traceability systems	Real-time visibility on supplier performance, carbon footprints, compliance, and risk	BAE Systems Australia + Ivalua: Source-to-Pay platform tracking 1,600+ suppliers
	Sustainability and compliance portals	Standardize data collection, supplier screening, and ESG reporting	Thales + Capgemini + Sweep (2025): Supplier-wide sustainability-data management platform; Thales: 400+ supplier action plans validated covering 50%+ of procurement carbon footprint; proprietary physical climate risk assessment tool
3. Knowledge & Capacity Building	Digital supplier training platforms	Virtual learning and compliance enablement for SMEs (cybersecurity, quality, environmental standards)	Lockheed Martin STEP (Supplier Training Excellence Program); Thales: Pacte PME Alliance for Decarbonization; Aero Excellence maturity framework (with Airbus, Dassault, Safran); AirCyber cybersecurity standard (430+ companies, via BoostAeroSpace)
	Capability assessments & joint problem-solving	Help SMEs meet defense-grade standards and production readiness	BAE Systems – Partnering4Success workshops & capability reviews
	Mentorship & operational support	Direct coaching to integrate SMEs into complex defense programs	BAE Systems & MBDA via DTEP engagement
4. Green Technology & Innovation	Product & component innovation	Low-carbon or resource-efficient alternatives to conventional defense components	Lockheed Martin Additive Manufacturing (Grand Prairie)**:** 10× faster output, 90% material savings; Thales: contrail avoidance calculator with Amelia (2,000-2,500 tCO2e avoided, 65%+ reduction per flight); Trixell reparability improvement (68% to 86%); CLOE and PETER eco-design tools

	Energy-efficient production systems	Reduce energy intensity in manufacturing processes	BAE Systems (Hunter-class frigates, Adelaide): Energy-efficient shipbuilding with SME modular production
	Advanced manufacturing & hybrid propulsion	Utilize breakthrough technologies to cut emissions and improve performance	Lockheed Martin AM applications in missile components manufacturing
5. Waste Management & Resource Efficiency	Critical-material traceability	Ensure responsible use, sourcing, and recycling of essential materials	Lockheed Martin (2024 Report)**:** Critical-mineral tracing + EcoVadis supplier assessments; Thales: European germanium recycling pathway for infrared optics; recycled titanium qualification at virgin-equivalent specs
	Closed-loop material recycling	Recover production scrap and reintegrate it into new components	Airbus Defense & Space**:** 90% closed-loop aluminum recycling for aerospace parts; Thales/Trixell: caesium iodide recycling line (75% material recovery, 30% lifecycle impact reduction)
	Supply-chain efficiency & waste reduction	Minimize scrap, improve yields, and reduce logistics waste	Defense OEMs using remanufacturing and parts-reuse frameworks (publicly referenced); Thales NewCORE program (sonar modernization through component reuse); EOLE end-of-life decision tool
6. Governance & Collaboration Models	Long-term supplier partnerships	Strengthen resilience via multi-year, performance-aligned relationships	BAE Systems – Partner2Win (2024)**:** Recognition of 90+ suppliers for quality, innovation, delivery; Thales: 15% CSR criterion in supplier selection since 2023; "Responsible Purchasing" label (ISO 20400)
	Joint cybersecurity & quality frameworks	Shared standards and collaborative risk management	Lockheed Martin STAR Supplier Program (awards high-performance suppliers such as M-Tron Components)
	Innovation-sharing & joint R&D	Co-development of technologies across the defense ecosystem	DTEP, plus major primes' R&D support to SMEs; Thales: 3,000+ startups referenced, 270 proofs of concept over the past decade

Exhibit 39 – Source: Ardabelle Capital interviews and analysis